THE NATIONAL EARTHQUAKE HAZARDS REDUCTION PROGRAM

HEARING

BEFORE THE

SUBCOMMITTEE ON BASIC RESEARCH

OF THE

COMMITTEE ON SCIENCE

U.S. HOUSE OF REPRESENTATIVES

ONE HUNDRED FOURTH CONGRESS

FIRST SESSION

OCTOBER 24, 1995

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THE NATIONAL EARTHQUAKE HAZARDS REDUCTION PROGRAM

TUESDAY, OCTOBER 24, 1995

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE,
SUBCOMMITTEE ON BASIC RESEARCH,
Washington, DC.

The Subcommittee met at 1 p.m. in Room 2318 of the Rayburn House Office Building, the Honorable Bill Baker, Acting Chairman, presiding.

Mr. BAKER. Thank you for your attention. The new Congress does meet on time, but Pete Geren is on his way here from his office and we are going to wait just a moment for him and we will begin.

Thank you so much for your attention.

[Pause.]

Mr. BAKER. My good friend, lead Democrat from Texas, Pete Geren is here. And, we are going to begin. And, I really appreciate your attention.

Without any objection, I am going to ask that the remarks of Steve Schiff, the Chairman of this Subcommittee, be entered into the record for your perusal. And, anyone else, any other member, that would like to enter remarks that isn't here, we will also do the same for them.

[The prepared statements of Mr. Schiff and Mr. Brown follow:]

PREPARED STATEMENT OF HON. STEVEN H. SCHIFF, CHAIRMAN OF THE SUBCOMMITTEE ON BASIC RESEARCH

Today the subcommittee will examine the National Earthquake Hazards Reduction Program (NEHRP) as well as two recently completed reports on NEHRP by the former Office of Technology Assessment (OTA) and the Earthquake Engineering Research Institute (EERI).

The impetus for NEHRP was and is the catastrophic loss of life and property suffered during earthquakes, particularly in California. We have all been horrified by the statistics of humans killed and injured and property damaged and destroyed by these disasters. However, earthquakes are by no means exclusive to California. Thirty-nine States are at some risk for a moderate to major earthquake in the near future. In fact, even my home State of New Mexico, hardly an earthquake center, experienced a series of small earthquakes this past summer.

NEHRP is currently administered by four Federal agencies, the Federal Emergency Management Agency (FEMA), the United States Geological Survey (USGS), the National Science Foundation (NSF), and the National Institute of Standards and Technology (NIST). Almost two-thirds of NEHRP funds go to earth science research administered by USGS and NSF. Fourteen percent of the NEHRP budget pays for structural engineering research at NIST. The remaining twenty-one percent is used by FEMA for overall coordination of NEHRP and implementation of Federal earthquake disaster mitigation programs.

NEHRP has led to a better understanding of why and where earthquakes have occurred; where they will probably occur in the future; and what happens to the Earth, to buildings and lifelines, and to people, when they occur. In addition, the research conducted through NEHRP helped in the development of new building designs, building codes, and reliability and risk assessment techniques that have reduced economic loss.

Despite the successes of NEHRP, the program has been criticized in past hearings and other venues for insufficient application of research results and technology developments. It is argued that there should be a stronger emphasis on the implementation of disaster mitigation programs. FEMA's implementation role, however, is limited to supplying information on earthquake risks and loss prevention. Because advances made in earthquake related research and engineering far outpace the implementation of new knowledge, some argue that the Federal Government should play a larger role in ensuring that disaster mitigation programs are implemented. Whether this should be accomplished through NEHRP or whether it is a Federal matter at all, are issues that need to be discussed.

NEHRP has also been criticized for lacking a clear strategy or set of goals. The OTA report recognizes this as an ongoing problem. I hope this issue will be addressed today as well.

Finally, I believe Congress needs to reassess the way we manage disaster assistance programs. Should the Federal Government tie disaster assistance to mitigation? Should we require high risk States and regions to implement mitigation programs, enforce building codes, or regulate land use in order to receive Federal assistance following a natural disaster? I realize this is a very controversial issue, and I am certainly not endorsing it at this time, but Federal spending in the coming years will be based on a very tight budget and this mandates that we do as much as possible toward preventing economic losses.

STATEMENT OF THE HONORABLE GEORGE E. BROWN, JR. AT THE NATIONAL EARTHQUAKE HAZARDS REDUCTION ACT REAUTHORIZATION HEARING

October 24, 1994

Mr. Chairman, I would like to commend you for convening this hearing. The National Earthquake Hazards Reduction Program has been instrumental in preparing communities for the inevitable ravages of earthquakes, both in California and across the nation. It is also a classic example of a federal program that promotes and utilizes basic and applied research for the benefit of the average taxpayer.

Recently, unexpected events have driven the need for further earthquake research. For instance, in the last few decades, scientists have discovered new earthquake hazards in the Pacific Northwest, the Central United States, and the New Madrid Region. In the last five years, the Whitier and Northridge earthquakes in Los Angeles broke along faults that did not even reach the surface--a phenomenon previously not thought possible by much of the science community. Since the Northridge earthquake, engineers have also recognized severe weaknesses in steel-framed buildings. These engineers had previously thought that steel-framed buildings were relatively safe in large earthquakes, so most skyscrapers were built using this technology. Now we find, however, that the welds in these structures break even in moderate-size earthquakes like the Northridge and Kobe quakes and that an unexpected threat exists to much of our building stock.

Without NEHRP, these problems would languish without a focussed research effort. With NEHRP, communities gain valuable time for the successful mitigation of these hazards. Mitigation of earthquake hazards is important--obviously--to the people who are directly affected like many who live in California and elsewhere. However, it is also important for the rest of the nation because of the keenly felt responsibility to respond and ameliorate the damage caused by natural disasters. The federal tab for the Northridge earthquake exceeded $13 billion and there is no reason to think that similar disasters are not in store for the future.

Finding a long-term approach to decrease the expense of natural disasters has become increasingly important in this budget climate. Taxpayers in different regions of the country, and their representatives in Congress, are increasingly hostile to having to pay for yet another earthquake, while allowing people to move right back in to where the trouble began. Without a long-term approach that has credibility with the public, this resistance to paying for others' problems will undoubtedly increase.

Through NEHRP, the community has made great strides in the development of buildings that withstand earthquakes, model building codes for all structures, and mapping to determine where such codes are most needed. However, as the Office of Technology Assessment points out, there are still gaps in implementation, for instance in the development of analytic tools to better inform communities of the costs and benefits of mitigation measures, and there are significant research efforts that NEHRP should undertake, for example increased applied geological research efforts.

In addition, as recommended by OTA, the Congress will hopefully begin a national dialogue on the federal responsibility toward the mitigation of, and response to, natural disasters such as earthquakes, through the discussion of NEHRP and of related bills on natural hazards insurance and protection.

We are fortunate today, because several reports have been issued recently on which we can draw. For instance, the Office of Technology Assessment performed a comprehensive analysis of the content of NEHRP, while the Office of Science and Technology Policy looked at NEHRP's internal organization. The most recent reauthorization of the Act also required OSTP to perform a study of earthquake engineering testing facilities to propose an approach to fill an oft-noted gap in the implementation and testing of new engineering concepts. Finally, the Federal Emergency Management Agency, responding to a previous legislative requirement, has produced a report on the protection of lifelines from earthquake-induced damage.

I look forward to hearing from our witnesses about the results of each of these studies and to discussing prospective changes for NEHRP. Again, Mr. Chairman, I commend you for convening this hearing and I look forward to working with you on the reauthorization of this important program. Thank you.

Mr. BAKER. Today, the Subcommittee on Basic Research is focusing on the National Earthquake Hazards Reduction Act. And, I am pleased to acknowledge that the former Chairman of the Science Committee, George Brown, is largely responsible for the organization of the National Earthquake Hazards Reduction Act.

Following the great earthquakes in Alaska, San Fernando, California in 1964 and 1971, Congress began to see a need for a federally-sponsored earthquake research program. Congressman Brown introduced legislation in the House, creating NEHRP, and vigorously pursued its enactment.

Today, NEHRP is a multi-agency program charged with researching, developing and disseminating information and technology to reduce earthquake hazards. NEHRP is administered by four federal agencies, including the United States Geological Survey, the Federal Emergency Management Agency, the National Science Foundation and the National Institute of Standards and Technology.

NEHRP can be credited with increasing our knowledge of seismic risk, enhancing our understanding of how buildings and other structures will fare during earthquakes and developing model building codes. Some of this knowledge has been applied in high risk seismic zones in California and other states.

But, it is clear from one of our states most recent earthquakes that implementation of technologically and scientifically advanced earthquake hazard and mitigation activities is still lagging. Disaster mitigation is critically important to the economic well-being of both my state, California, and of the nation.

We cannot continue to absorb billions of dollars of economic losses, as was the case in the Northridge earthquake in 1994 and in the Loma Prieta earthquake in 1989, to say nothing of the loss of lives. I believe we must enact legislation that will ensure a greater role for hazard mitigation before disaster strikes again.

For example, I've co-sponsored legislation introduced by Representative Bill Emerson, H.R. 1856, the Natural Disaster Protection Partnership Act, which establishes incentives for building code enforcement and land use planning. In addition, this legislation addresses the shortage of disaster insurance by creating a privately-owned corporation which will enable insurers to join forces to better provide insurance to home and business owners in risk prone areas.

This is a compelling need for states like mine. Nearly 75 percent of the victims of California's Northridge earthquake were uninsured, a trend which continues even after this devastating event.

Although we cannot prevent natural disasters such as earthquakes, we can plan intelligently to minimize the financial and physical harm they cause by coupling effective research programs like NEHRP with programs that provide incentives for implementing disaster mitigation programs. I realize the legislation I've described is somewhat separate from the thrust of NEHRP's research program and that the other committees of Congress have jurisdiction over it, but it's vital to our earthquake mitigation efforts.

Before I recognize the first panel of witnesses to begin their testimony, I would like to recognize Mr. Peter Geren for an opening statement. Pete.

Mr. GEREN. Thank you, Mr. Chairman. I want to congratulate the Subcommittee Chairman for convening this hearing and for taking an interest in natural disaster research.

Fortunately, the district I represent in Texas has not experienced devastating earthquakes and the long-term damage they wreak. However, earthquakes are not unknown in Texas and certainly are experienced in many other states throughout our nation.

Earthquakes, like the Loma Prieta and Northridge events in California, are unavoidable natural disasters that affect the nation at large when they occur. From my limited acquaintance with the National Earthquake Hazards Reduction Program, I found a program that has successfully focused on short and long-term approaches to mitigating the damage from earthquakes.

The program has also served as a model for the rapid dissemination of basic and applied research advances to the advantage of all Americans. I think that we all wish the program continued success and are meeting today to see how that can happen within the strict budget climate.

I am glad to be here to learn more about NEHRP but also to begin a discussion of the Federal role in natural disaster protection and relief. In Texas, we have hurricanes, floods and tornados. As our state experiences these problems, so has every other state in the nation.

Natural disasters are a nationwide problem. And, the Federal Government seldom gets off the hook when natural disasters occur.

In the long-term, research and technology development are key to our nation's ability to mitigate and respond to natural disasters. So, I welcome the chance today to consider long-term actions as opposed to simply responding to each natural disaster as it comes.

I look forward to the testimony of the witnesses. And, I want to thank each one of them for appearing before the Subcommittee today.

Thank you, Mr. Chairman.

Mr. BAKER. Peter, thank you. Mr. Bartlett, do you have a little word for the guests?

Mr. BARTLETT. Thank you very much. We have not had an earthquake in our area of the country for a long while now, but I noted, with interest, on a map that there is a major fault line that runs not too far from us. And, so it's not—it would not be unanticipated that there would be one in the future.

Of course, what hurts one of us hurts all of us. And, so I am happy to be here today to attend this meeting.

Thank you very much for convening it. And, welcome to the panelists.

Thank you.

Mr. BAKER. And, as one of the three scientists on this Committee, you will probably be the only one that understands what is being said here today, Dr. Bartlett. So, we will count on you.

Our first two witnesses were asked to be here today to discuss separately recent completed reports on NEHRP. Dr. Paul Komor, representing the former Office of Technology Assessment, is here to present OTA's report. And, Dr. Dan Abrams, representing the Earthquake Engineering Research Institute, will discuss a report

EERI was contracted to do, as mandated by the most recent NEHRP reauthorization.

Without objection, both reports will be made part of the hearing record. And, all written testimony submitted today at the request of the Subcommittee will also be made part of the hearing record.

Dr. Komor and Dr. Abrams, you are both here. Okay. Go ahead.

STATEMENT OF DR. PAUL KOMOR, FORMER PROJECT DIRECTOR, OFFICE OF TECHNOLOGY ASSESSMENT

Mr. KOMOR. Mr. Chairman and members of the Subcommittee, I appreciate the opportunity to testify today. My testimony draws from an Office of Technology Assessment report entitled "Reducing Earthquake Losses," although my testimony today reflects my own beliefs and views and not necessarily those of the Office of Technology Assessment.

I would like to make five major points in my testimony today. Point Number 1. Much of the U.S. is at risk from earthquakes.

The greatest likelihood of U.S. earthquakes is in the coastal regions of California. However, other regions of the U.S., including the Pacific Northwest, the western mountain states and sections of the central and eastern U.S., have experienced infrequent earthquakes in the past.

Future occurrences are very uncertain. But, if and when they do occur, losses—that is, deaths, injuries and financial and social damage—could be quite high, as these areas are largely unprepared. Although future losses are uncertain, there is general agreement that damaging earthquakes will strike the United States in the next few decades, causing at the minimum dozens of deaths and tens of billions of dollars in losses.

Point Number 2. Although earthquakes are unavoidable, the losses they cause can be reduced through greater application of existing knowledge.

In the two recent California earthquakes, for example, modern structures meeting current building codes and incorporating known earthquake-resistant practices did not collapse. Even in the disastrous 1995 Kobe, Japan earthquake, modern structures remained standing.

This is not to say that we know all we need to about earthquake science and engineering. Many uncertainties remain. However, it is clear that greater use of existing knowledge would reduce losses significantly.

Point Number 3. The Federal Earthquake Program, NEHRP, has made major contributions toward improving our understanding of earthquakes.

The Federal Government currently responds to the earthquake threat with a number of policies and programs. Its primary effort is the National Earthquake Hazards Reduction Program, established in 1977.

The program combines the effort of four federal agencies—the U.S. Geological Survey, the National Science Foundation, the Federal Emergency Management Agency and the National Institute of Standards and Technology. The program has centered on the support of science and engineering research.

Approximately 64 percent of the NEHRP budget goes towards research in the earth sciences. And, 14 percent supports engineering research. The remaining 22 percent of the budget goes to implementation activities such as technical translation, education and outreach.

Examples of NEHRP contributions include NEHRP-supported research that led to recognition of the seismic risk in the Pacific Northwest and NEHRP funding that helped develop the knowledge base that now makes it possible to design and construct new buildings that are unlikely to collapse in an earthquake.

Although NEHRP is principally a research program, it has made some contributions towards implementation of earthquake knowledge and mitigation as well. For example, we now have model building codes that reflect a national consensus on new building seismic design.

Point Number 4. Much of NEHRP-generated knowledge has not been applied, leaving the U.S. at risk for major earthquake losses.

The failure to implement known technologies and practices is a direct result of NEHRP's approach to reducing earthquake losses. NEHRP's approach is to supply information on earthquake risks and possible countermeasures to those who may wish to mitigate.

This approach implicitly assumes that the interest or incentive for mitigation is sufficient for people to act on such information. However, the current paucity of mitigation activities suggests that individuals, organization and local and state governments often lack incentives for mitigation.

Whether or not the Federal Government should play a role in ensuring that there are sufficient incentives for mitigation is a sensitive policy question. In any case, however, NEHRP's approach of supplying information alone clearly limits the program's impact.

NEHRP faces serious operational problems as well. Numerous congressional reports and expert review panels have noted that NEHRP lacks clear and workable goals and strategies.

NEHRP spending by the four participating agencies does not suggest any unified multi-agency agreement on specific goals, strategies or priorities. In the absence of a multi-agency consensus, each of the four participating agencies has developed a portfolio of NEHRP activities that largely reflect the agency's own mission and priorities.

Point Number 5. OTA has identified policy options that Congress could consider to improve Federal efforts to reduce earthquake losses.

Three types of policy options are identified. Type Number 1. Changes in the specific research and other activities that NEHRP undertakes; type Number 2, management and operational changes in NEHRP; and, type Number 3, changes to federal disaster assistance and related programs.

I will briefly discuss a few examples of each type. Under changes in specific activities of NEHRP, earth science research accounts for almost two-thirds of NEHRP money and the earth science portfolio supported by NEHRP includes a range of activities but leans towards more basic earth science research. Decisions about what type of earth science research to support under NEHRP should be made in the context of the goals of the program.

If Congress would like NEHRP to reduce earthquake losses in the short-term and to focus on implementing known technologies and practices, then the earth science portfolio should favor more applied short-term work, such as microzonation and ground motion mapping. In contrast, if Congress views NEHRP as a program for reducing earthquake risk over the long-term, then it would be appropriate to retain the current focus towards basic earth science research.

Under earthquake engineering research, new structures meeting current seismic codes are unlikely to collapse in an earthquake and are, therefore, unlikely to cause many deaths. However, even new structures will likely suffer expensive non-structural and contents damage. Research into ways to reduce this expensive damage could be given higher priority.

Under implementation, one of NEHRP's most promising implementation activities is to directly assist communities in their efforts to understand earthquake risks and to devise mitigation options. Tools to estimate likely losses in the event of a future earthquake and to predict the likely benefits of mitigation would be of great help to communities.

Also, options of the second type, management and operational changes in NEHRP. NEHRP spending by the four participating agencies suggests a loosely coordinated confederation of agencies with no overarching agreement on specific goals, strategies or priorities.

One policy option is for FEMA, as the lead agency, to work with other NEHRP agencies and with the professional earthquake community to come up with specific goals and priorities for NEHRP. Congress could require FEMA to report on progress towards defining and meeting these specific 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-upon goals.

Policy options of Type Number 3, changes to federal disaster assistance and related programs. Options include using federal disaster assistance as an incentive for mitigation, an increased federal role in disaster insurance, and greater use of financial incentives to promote mitigation.

These policy options have the potential to significantly increase implementation of seismic safety knowledge, 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 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.

One policy option, largely outside the scope of NEHRP as currently defined, would be for the Federal Government to require states and localities to adopt model building codes or to demonstrate a minimum level of code enforcement as a condition for receiving federal disaster aid.

To summarize, the United States will experience damaging earthquakes in the next few decades. This damage could be reduced through greater use of known technologies and practices.

NEHRP has, to date, done much to expand this knowledge. A key remaining challenge is putting this knowledge to use.

Thank you.

[The prepared statement and attachments of Dr. Komor follow:]

REDUCING EARTHQUAKE LOSSES

TESTIMONY OF PAUL KOMOR
FORMER PROJECT DIRECTOR
OFFICE OF TECHNOLOGY ASSESSMENT

Accompanied by

KELLEY SCOTT
FORMER SENIOR ANALYST
OFFICE OF TECHNOLOGY ASSESSMENT

Before the

HOUSE COMMITTEE ON SCIENCE
SUBCOMMITTEE ON BASIC RESEARCH

24 October 1995

Mr. Chairman and Members of the Committee:

We appreciate the opportunity to testify today on technologies and policies to reduce earthquake losses. Our testimony draws from an Office of Technology Assessment report entitled *Reducing Earthquake Losses*. This report was requested by this Committee in March 1994 and was delivered to the Congress in September 1995. Chapter 1 of the report, which summarizes the key findings of the report and discusses the policy options, is provided as an attachment to this testimony. Copies of the full report are available through the Government Printing Office.

I was the Project Director and Kelley Scott was the Senior Analyst for the report. However, our testimony today reflects our own beliefs and views and not necessarily those of the Office of Technology Assessment.

1. MUCH OF THE U.S. IS AT RISK FROM EARTHQUAKES.

The earthquake risk varies widely from region to region:

- The greatest likelihood of U.S. earthquakes is in the coastal regions of California, where moderate earthquakes are frequent and population densities are high. California, in addition, faces a lower probability of larger, very damaging earthquakes.
- The Pacific Northwest has experienced rare but very large earthquakes in the past; the timing of future earthquakes in this region of the country is uncertain.
- Earthquakes in the section of the Intermountain West running from southern Idaho and western Montana through Utah and Nevada can endanger communities historically unprepared for any seismic activity.
- The central United States (chiefly, the region near the intersection of Missouri, Kentucky, Tennessee, and Arkansas) and sections of the eastern United States have experienced infrequent earthquakes in the past. Future occurrences are very uncertain, but if and when they do occur, losses could be quite high as these areas are largely unprepared.

The primary hazard associated with earthquakes is ground shaking, which damages and destroys buildings, bridges, and other structures. Ground shaking also causes liquefaction, landslides, and other ground failures that can damage structures. This damage and destruction has both short- and long-term implications. In the short term, people are killed and injured by falling buildings and other objects. The fires associated with earthquakes are often difficult to fight because water pipes have been broken and roads have been 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 close. Local governments may be forced to cut services to cover the costs of infrastructure repair. And if reductions in the supply of housing lead to higher rents, there may be increased homelessness.

Although future losses are uncertain, there is general agreement that **damaging earthquakes will strike the United States in the next few decades, causing at the**

minimum dozens of deaths and tens of billions of dollars in losses.

2. ALTHOUGH EARTHQUAKES ARE UNAVOIDABLE, THE LOSSES THEY CAUSE CAN BE REDUCED THROUGH GREATER USE OF EXISTING KNOWLEDGE.

In the two recent California earthquakes, for example, modern structures meeting current building codes and incorporating known earthquake-resistant practices generally performed quite well. Even in the disastrous 1995 Kobe, Japan earthquake, modern structures generally performed quite well.

This is not to say that we know all we need to about earthquake science and engineering: many significant uncertainties remain, including for example the surprising damage done to modern steel structures in the 1994 Northridge earthquake. However, it is clear that greater use of existing knowledge would reduce losses significantly. Examples of our failure to use existing knowledge include:

- In much of the U.S., seismic building codes are not adopted or not enforced.
- Few communities outside of California have addressed the difficult problem of upgrading the existing building stock.
- Many bridges in the U.S. are susceptible to significant earthquake damage.

3. THE FEDERAL EARTHQUAKE PROGRAM--NEHRP--HAS MADE SIGNIFICANT CONTRIBUTIONS TOWARD IMPROVING OUR UNDERSTANDING BOTH OF EARTHQUAKES AND OF STRATEGIES TO REDUCE THEIR IMPACT.

The federal government currently responds to the earthquake threat with a number of policies and programs. Its primary effort is the National Earthquake Hazard Reduction Program (NEHRP), established in 1977 to "reduce the risks of life and property from future earthquakes in the U.S...." The 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).

NEHRP's original charter included wide-ranging provisions for earthquake prediction, earthquake control, and vigorous implementation of seismic safety knowledge. In practice, however, the program has centered on the support and dissemination of science and engineering research. Thus, 64 percent of the NEHRP budget goes (via USGS and NSF) to research in the earth sciences, and another 14 percent supports engineering research; the remaining 22 percent of the budget goes to "implementation" activities such as technical translation, education, and outreach.

Examples of NEHRP contributions include NEHRP-supported research that led to recognition of the seismic risk in the Pacific Northwest, and NEHRP funding that helped develop the knowledge base that now makes it possible to design and construct new buildings that are unlikely to collapse in earthquakes. Although NEHRP is principally a research program--over 75 percent of its funds are directed toward research--it has made some contributions to the implementation of earthquake mitigation, as well. Thus, 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.

4. THE U.S. REMAINS AT RISK FOR MAJOR EARTHQUAKE LOSSES, AND IT IS NOT CLEAR THAT NEHRP IN ITS CURRENT FORM WILL SIGNIFICANTLY REDUCE THIS RISK.

Earthquakes continue to 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,[1] **there is clearly a significant remaining exposure to earthquake damage--due in large part to a failure to implement known technologies and practices.** Many communities, especially in California, have taken steps to reduce earthquake losses, but there still remains a large gap between what current knowledge says could be done and what actually is done.

The failure to implement known technologies and practices, or "implementation gap," is a direct result of NEHRP's approach to reducing earthquake losses. NEHRP's approach 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 by 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 current paucity of mitigation activities suggests that individuals, organizations, and local and state governments often lack incentives for mitigation. Whether or not the federal government should play a role in ensuring that there are sufficient incentives for mitigation is a sensitive policy question. In any case, **NEHRP's approach of supplying information alone clearly limits the program's impact.**

NEHRP faces serious operational problems as well. Numerous congressional reports and expert review panels have noted that **NEHRP lacks clear and workable goals and strategies.** Although NEHRP's authorizing legislation does set broad overall objectives

[1] Although no losses would seem desirable, achieving zero losses would be either impossible or impractically expensive

for the program, actual NEHRP spending by the four participating agencies does not suggest any unified multiagency agreement on specific goals, strategies, or priorities. In the absence of a multiagency consensus on NEHRP goals and strategies, each of the four participating agencies (USGS, NSF, FEMA, and NIST) has developed a portfolio of NEHRP activities that reflects its own agency mission and priorities. In addition, the lack of agreement on goals and strategies makes it difficult to judge the impact or success of the overall program, since there are few criteria by which to measure performance.

5. OTA HAS IDENTIFIED SEVERAL POLICY OPTIONS THAT CONGRESS COULD CONSIDER TO IMPROVE FEDERAL EFFORTS TO REDUCE EARTHQUAKE LOSSES.

Three general types of policy options are discussed here:

- **changes in the specific research and other activities that NEHRP undertakes.** OTA identifies key research and implementation needs that NEHRP could address within its current scope.
- **management and operational changes in NEHRP.** Such changes could make NEHRP a more efficient, coordinated, and productive program.
- **changes to federal disaster assistance and insurance, regulation, and financial incentives.** Such changes are outside the current scope of NEHRP and would represent a significant change in direction for the program. However, **such changes are necessary to yield major national reductions in earthquake risk.**

-CHANGES IN SPECIFIC ACTIVITIES OF NEHRP

Earth Science Research

Decisions about what earth science research to support should be made in the context of the goals of the earthquake program. If Congress would like NEHRP to reduce earthquake losses in the short term and also to focus on implementing known technologies and practices, then the earth science research portfolio should favor more applied, short-term work such as microzonation, ground motion mapping, and hazard assessment. In contrast, if Congress views NEHRP as a program for reducing earthquake hazards over the long term, it would be appropriate to retain the current focus on basic earth science research.

Earthquake Engineering Research

A new structure that meets current seismic building codes will be very resistant to collapse due to earthquakes. The construction of buildings that are resistant to collapse 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 earthquake-related structural, nonstructural, and contents damage. Although data are scarce, it appears that much of the damage in recent earthquakes was due not to collapse, but to these other types of damage.

Much of the risk of both collapse and other types of damage lies in existing structures, which do not incorporate current codes and knowledge. Relatively few of these structures have been retrofitted to reduce risk; and where retrofits have been performed they have often been expensive, complex, and of uncertain benefit. More research is needed to improve retrofit methods.

Implementation

One of NEHRP's most promising implementation activity is to directly assist communities in their efforts to understand earthquake risk and to devise mitigation options. Analytic tools to estimate likely losses in the event of a future earthquake and to predict the likely benefits of mitigation would be of great help to communities.

FEMA currently has several programs intended to promote implementation of known mitigation technologies and practices. 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, and why. All mitigation programs should be evaluated carefully, and the results should be used to improve, refocus, or--if necessary--terminate programs.

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 issues that currently hinder mitigation.

-MANAGEMENT AND OPERATIONAL CHANGES IN NEHRP

NEHRP spending by the four participating agencies suggests a loosely coordinated confederation of agencies with no overarching agreement on specific goals, strategies, or priorities for NEHRP. One policy option is for FEMA, as the lead agency, to work with other NEHRP agencies and with the professional earthquake community to come up with specific goals and priorities for NEHRP. Defining overarching goals for NEHRP would not be easy and would have to address the difficult issue of acceptable risk. Yet it is necessary for NEHRP to move beyond a loose confederation of four agencies. Congress could require FEMA to report on progress toward defining and meeting specific goals for NEHRP. 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 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. One policy option would be for Congress to allow FEMA to continue as lead agency but to provide frequent oversight to ensure that lead agency responsibilities are carried out.

-BEYOND THE CURRENT NEHRP

Congress could consider other policy options that go beyond the scope of the current NEHRP. These include using federal disaster assistance as an incentive for mitigation, an increased federal role in disaster insurance, increased regulation, and greater use of financial incentives to promote mitigation. These policy options have the potential to significantly increase implementation of seismic safety knowledge--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 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.

Insurance and disaster assistance can be a vehicle for mitigation, as well as a disincentive against mitigation, depending on how the program is structured. Insurance can be a strong incentive for earthquake damage 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. Insurance programs should recognize these complexities.

One policy option, 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 is typically a state or local responsibility. The federal government plays only an indirect role by providing technical support for code development and implementation. In addition, Executive Order 12699 (issued January 5, 1990) requires that new buildings constructed with federal assistance meet current codes. A more aggressive policy option would be to require states and localities to adopt model building codes, or demonstrate a minimum level of code enforcement, as a condition for receiving federal aid. Nonstructural mitigation efforts could be advanced through an executive order addressing this problem in federal buildings.

To summarize, the U.S. will experience damaging earthquakes in the next few decades. This damage could be reduced--but not eliminated--through greater use of known technologies and practices. NEHRP has to date done much to expand this knowledge; a key remaining challenge is putting this knowledge to use.

Office of Technology Assessment Congress of the United States

REDUCING EARTHQUAKE LOSSES

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Foreword

Much of the nation is at risk for earthquakes. Although considerable uncertainty remains over where and when future earthquakes will occur, there is general consensus that earthquakes will strike the United States in the next few decades, causing at a minimum dozens of deaths and tens of billions of dollars in losses.

Recent congressional hearings on the nation's earthquake program—the National Earthquake Hazards Reduction Program (NEHRP)—revealed some dissatisfaction with the program, yet little agreement on problems or solutions. The House Committee on Science, Space, and Technology (now the Committee on Science) and its Subcommittee on Science (now the Subcommittee on Basic Research) asked the Office of Technology Assessment to review the nation's efforts to reduce earthquake losses, and to provide options for improving these efforts.

This Report assesses the state of the knowledge, identifies key future challenges in each of the three components of earthquake risk reduction—earth science, engineering, and implementation—and offers policy options to improve federal efforts. The Report concludes that, since its beginning in 1977, NEHRP support of efforts to better understand earthquake risk and find ways to reduce it have advanced our knowledge considerably, although many significant uncertainties remain. However, there is a large gap between knowledge and action—many known technologies and practices are just not used. In addition, NEHRP suffers from a lack of specific goals, making progress difficult to measure. Policy options for improving federal efforts include changes in the specific activities supported by NEHRP, changes in the management and operations of the program, and extension of federal activities into areas in which NEHRP is not currently active.

OTA benefited greatly from the substantial assistance received from many organizations and individuals in the course of this study. Members of the advisory panel, the reviewers, and many others willingly lent their time and expertise; OTA and the project staff are grateful for their assistance.

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Note: OTA appreciates and is grateful for the valuable assistance and thoughtful critiques provided by the advisory panel members. The panel does not, however, necessarily approve, disapprove, or endorse this report. OTA assumes full responsibility for the report and the accuracy of its contents.

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Executive Summary

The 1994 Northridge, California, earthquake caused dozens of deaths and over $20 billion in losses. In 1995 an earthquake in Kobe, Japan, killed more than 5,000 and resulted in losses of well over $100 billion. These disasters show the damage earthquakes can inflict. Although future losses are uncertain, there is general agreement that **damaging earthquakes will strike the United States in the next few decades, causing at the minimum dozens of deaths and tens of billions of dollars in losses.**

Since 1977, the federal government has had a research-oriented program to reduce earthquake losses. This program—the National Earthquake Hazard Reduction Program (NEHRP)—has made significant contributions toward improving our understanding of earthquakes and strategies to reduce their impact. However, much of the United States remains at risk for significant earthquake losses. Risk-reduction efforts lag far behind the knowledge base created by research; this lag, or "implementation gap," reflects the limitations of NEHRP's information-based strategy for encouraging nonfederal action. NEHRP also suffers from a lack of clear programmatic goals.

THE EARTHQUAKE THREAT

Much of the United States is seismically active. Risks vary widely from region to region:

- The greatest likelihood of repeated economic losses due to earthquakes is in the coastal regions of California, where moderate earthquakes are frequent and population densities are high. California, in addition, faces a lower probability of larger, very damaging earthquakes.
- The Pacific Northwest has experienced rare but very large earthquakes in the past; the timing of future earthquakes in this region of the country is uncertain.
- Quakes in the section of the Intermountain West running from southern Idaho and western Montana through Utah and Nevada can endanger communities historically unprepared for any seismic activity.
- The central United States (chiefly, the region near the intersection of Missouri, Kentucky, Tennessee, and Arkansas) and sections of the eastern United States have experienced infrequent earthquakes in the past. Future occurrences are very uncertain, but if and when they do occur, losses could be quite high as these areas are largely unprepared.

The primary hazard associated with earthquakes is ground shaking, which damages and destroys buildings, bridges, and other structures. Ground shaking also causes liquefaction, landslides, and other ground failures that endanger structures. This damage and destruction has both short- and long-term implications. In the short term, people are killed and injured by falling buildings and other objects. The fires associated with earthquakes are often difficult to fight because water pipes have been broken and roads have been 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 close. Local governments may be forced to cut services to cover the costs of infrastructure repair. And if reductions in the supply of housing lead to higher rents, there may be increased homelessness.

THE U.S. POLICY RESPONSE TO DATE

The federal government currently responds to the earthquake threat with a number of policies and programs. Its primary effort is the National Earthquake Hazard Reduction Program (NEHRP), established in 1977 to "reduce the risks of life and property from future earthquakes in the U.S...." The 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).

NEHRP's original charter included wide-ranging provisions for earthquake prediction, earthquake control, and vigorous implementation of seismic safety knowledge. In practice, however, the program has centered on the performance and dissemination of science and engineering research. Thus, 64 percent of the NEHRP budget goes (via USGS and NSF) to research in the earth sciences, and another 14 percent supports engineering research; the remaining 22 percent of the budget goes to "implementation" activities such as technical translation, education, and outreach.

NEHRP: PROGRESS AND PROBLEMS

NEHRP-sponsored research has yielded an impressive list of accomplishments. Although past accomplishments do not ensure future ones, it is clear that **NEHRP has led to significant advances in our knowledge of both earth science and engineering aspects of earthquake risk reduction.** For example, NEHRP-supported research led to recognition of the seismic risk in the Pacific Northwest, and NEHRP funding helped develop the knowledge base that now makes it possible to design and construct new buildings that are unlikely to collapse in earthquakes. Although NEHRP is principally a research program—over 75 percent of its funds are directed toward research—it has made some contributions to the implementation of earthquake mitigation, as well. Thus, 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 continue to 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,[1] **there is clearly a significant remaining exposure to earthquake damage—due in large part to a failure to implement known technologies and practices.** Many communities, especially in California, have taken steps to reduce earthquake losses, but there still remains a large gap between what current knowledge says could be done and what actually is done.

The failure to implement known technologies and practices, or "implementation gap," is a direct result of NEHRP's approach to reducing earth-

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

quake losses. NEHRP's approach 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 current paucity of mitigation activities suggests that individuals, organizations, and local and state governments lack sufficient incentives for mitigation. Whether or not the federal government should play a role in ensuring that there are sufficient incentives for mitigation is a sensitive policy question. In any case, **NEHRP's approach of supplying information alone clearly limits the program's impact.**

NEHRP faces serious operational problems as well. Numerous congressional reports and expert review panels have noted that **NEHRP lacks clear and workable goals and strategies.** Although NEHRP's authorizing legislation does set broad overall objectives for the program, actual NEHRP spending by the four participating agencies does not suggest any unified multiagency agreement on specific goals, strategies, or priorities. In the absence of a multiagency consensus on NEHRP goals and strategies, each of the four participating agencies (USGS, NSF, FEMA, and NIST) has developed a portfolio of NEHRP activities that reflects its own agency mission and priorities. In addition, the lack of agreement on goals and strategies makes it difficult to judge the impact or success of the overall program, since there are few criteria by which to measure performance.

POLICY OPTIONS

OTA has identified several policy options that Congress could consider to improve federal efforts to reduce earthquake losses. Three general types of policy options are discussed:

- One type of option involves changes in the specific research and other activities that NEHRP undertakes. OTA identifies key research and implementation needs that NEHRP could address within its current scope.
- The second type of option involves management and operational changes in NEHRP. Such changes could make NEHRP a more efficient, coordinated, and productive program.
- The third type of option includes changes to federal disaster assistance and insurance, regulation, and financial incentives. Such changes are outside the current scope of NEHRP and would represent a significant change in direction for the program. However, **such changes are necessary to yield major national reductions in earthquake risk.**

CHANGES IN SPECIFIC ACTIVITIES OF NEHRP

Earth Science Research

Decisions about what earth science research to support should be made in the context of the goals of the earthquake program. If Congress would like NEHRP to reduce earthquake losses in the short term and also to focus on implementing known technologies and practices, then the earth science research portfolio should favor more applied, short-term work such as microzonation, ground motion mapping, and hazard assessment. In contrast, if Congress views NEHRP as a program for reducing earthquake hazards over the long term, it would be appropriate to retain the current focus on basic earth science research.

Earthquake Engineering Research

A new structure that meets current seismic building codes will be very resistant to collapse due to earthquakes. The construction of buildings that are resistant to collapse 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 earthquake-related structural, nonstructural, and contents damage.

Much of the risk of both structural failure and nonstructural and contents damage lies in existing structures, which do not incorporate current codes and knowledge. Relatively few of these structures have been retrofitted to reduce risk; and where retrofits have been performed they have often been expensive, complex, and of uncertain benefit. More research is needed to improve retrofit methods.

▮ Implementation

One of NEHRP's most promising implementation activity is to directly assist communities in their efforts to understand earthquake risk and to devise mitigation options. Analytic tools to estimate likely losses in the event of a future earthquake and to predict the likely benefits of mitigation would be of great help to communities.

FEMA currently has several programs intended to promote implementation of known mitigation technologies and practices. 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, and why. All mitigation programs should be evaluated carefully, and the results should be used to improve, refocus, or—if necessary—terminate programs.

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 issues that currently hinder mitigation.

MANAGEMENT AND OPERATIONAL CHANGES

NEHRP spending by the four participating agencies suggests a loosely coordinated confederation of agencies with no overarching agreement on specific goals, strategies, or priorities for NEHRP. One policy option is for FEMA, as the lead agency, to work with other NEHRP agencies and with the professional earthquake community to come up with specific goals and priorities for NEHRP. Defining overarching goals for NEHRP would not be easy and would have to address the difficult issue of acceptable risk. Yet it is necessary for NEHRP to move beyond a loose confederation of four agencies. Congress could require FEMA to report on progress toward defining and meeting specific goals for NEHRP. 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 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. One policy option would be for Congress to allow FEMA to continue as lead agency but to provide frequent oversight to ensure that lead agency responsibilities are carried out.

BEYOND THE CURRENT NEHRP

Congress could consider other policy options that go beyond the scope of the current NEHRP. These include using federal disaster assistance as an incentive for mitigation, an increased federal role in disaster insurance, increased regulation, and greater use of financial incentives to promote mitigation. These policy options have the potential to significantly increase implementation of seismic safety knowledge—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 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 but rather suggests that policymakers consider the policy options in light of their own beliefs.

Insurance and disaster assistance can be a vehicle for mitigation, as well as a disincentive against mitigation, depending on how the program is structured. Congressional decisions as to the fate of hazards insurance legislation will involve many issues, most of which are beyond the scope of this report. With respect to mitigation, however, it is clear that 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. Insurance programs should recognize these complexities.

One policy option, 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 only an indirect role by providing technical support for code development and implementation. In addition, Executive Order 12699 (issued January 5, 1990) requires that new buildings constructed with federal assistance meet current codes. A more aggressive policy option would be to require states and localities to adopt model building codes, or demonstrate a minimum level of code enforcement, as a condition for receiving federal aid. Nonstructural mitigation efforts could be advanced through an executive order addressing this problem in federal buildings.

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

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[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.

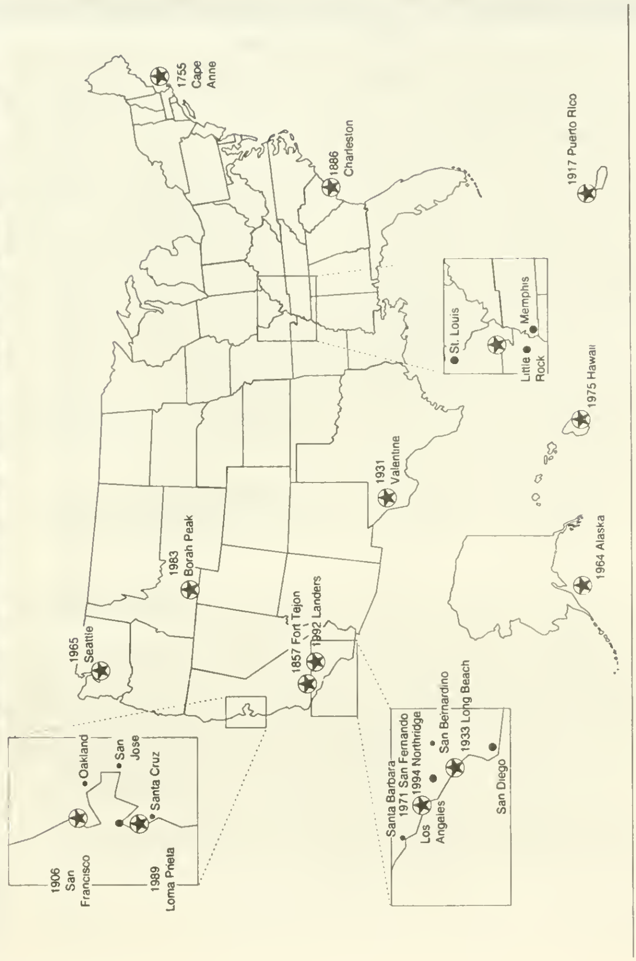
[2] Working Group on California Earthquake Probabilities, *Probabilities of Large Earthquakes in the San Francisco Bay Region, California*, U.S. Geological Survey Circular 1053 (Washington, DC: U.S. Government Printing Office, 1990).

[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.[1]

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 billion.[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	LoCalifornlation	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 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, 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

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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 homelessness.

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 1-1). 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,

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

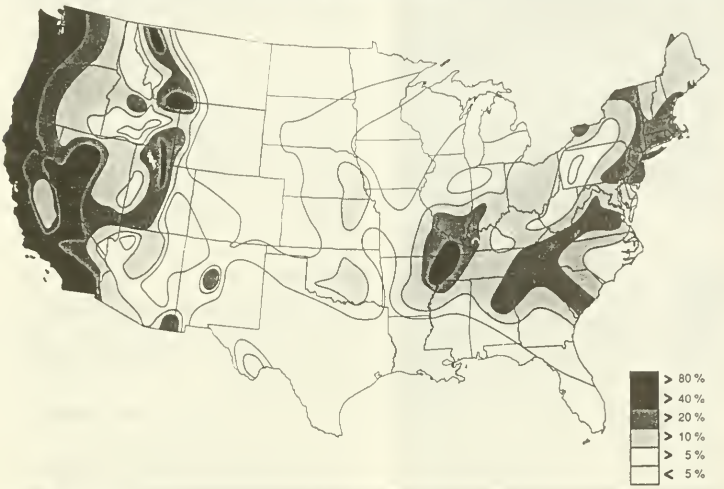
[7] B. Bolt, *Earthquakes* (New York, NY: W. H. Freeman and Co., 1993), pp. 272-273.

[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 Hazard Map



NOTE Map shows expected ground acceleration as a percentage of gravitational acceleration (100% = 1.0 G) This expected acceleration is for 0.3-second period shaking and has a 10% probability of being exceeded in 50 years

SOURCE Office 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, 271.

[13] Durkin and Thiel, see footnote 11.

EARTHQUAKE ENGINEERING RESEARCH INSTITUTE

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—the 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 burn 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 homelessness and dislocation. Communities faced with the huge costs of repairing earthquake-induced damage to public property may be 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.

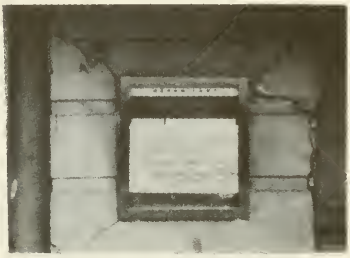
In addition to the intermittent large supplemental appropriations to cover some of the costs of earthquakes, the federal government currently spends about $100 million annually on NEHRP—

[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

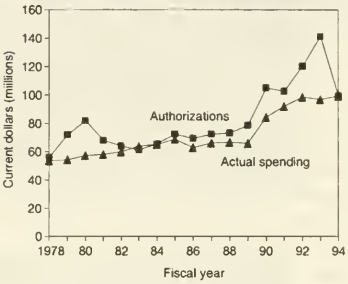
The use of mitigation technologies and practices increases upfront (initial) costs. These costs can be calculated with reasonable certainty, and they can be considerable. For example, the estimated cost to seismically retrofit buildings at one campus of the University of California is $500 million.[20] 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: Office 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.

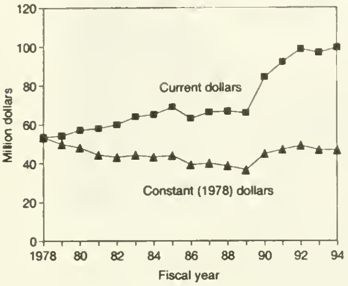
A number of federal agencies have earthquake mitigation research and implementation programs that deal with specific earthquake risks faced by these agencies. The Department of Veteran's Affairs, the Department of Energy, the Department of Defense, the National Aeronautics and Space Administration, the 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).

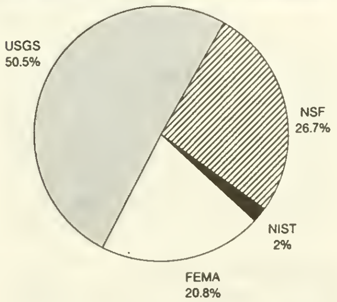
There is no NEHRP agency or central office. Rather, NEHRP is a program in which four federal agencies—USGS, NSF, FEMA, and NIST—participate. **Almost two-thirds of NEHRP funds go for earth science research**—via USGS and NSF earth science programs (see figure 1-5). Fourteen percent is used for engineering 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



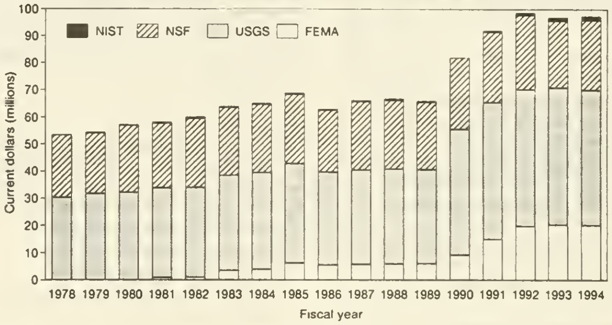
KEY: USGS = U.S. Geological Survey, NSF = National Science Foundation, FEMA = Federal Emergency Management Agency, NIST = National Institute of Standards and Technology

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 Whitcomb, 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—so 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*, NEHRP FY 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-induced 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 Reduction Program*, U S Geological Survey Circular 1079 (Washington, DC U S Government Printing Office, 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).

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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.

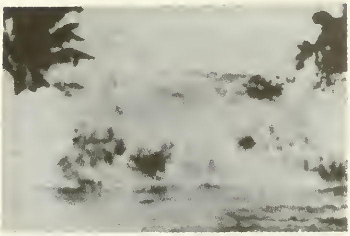
Historically, NEHRP has focused on basic research that contributes primarily to the first objective and, to a much lesser degree, on disseminating research results to the public. In large part, this is due to the absence of clear goals or strategies for the program, an issue discussed in greater detail 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 I-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, General Accounting Office, "Loma Prieta Earthquake: Collapse of the Bay Bridge and the Cypress Viaduct," GAO/RCED-90-177, June 1990, p. 2.

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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 modern 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.

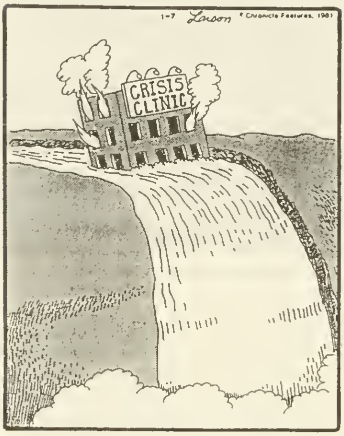
Better evaluation of FEMA implementation programs is needed. Very few of these programs have been evaluated carefu'ly in the past, leaving current program planners with little guidance as to what works, what does not work, and why. All mitigation programs should be evaluated carefully, and the results 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.



Some areas of the U.S. 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.

[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.

Understanding Seismic Hazards 2

Earthquakes remind us that the earth is continually changing, sometimes with disastrous consequences for its inhabitants and for the relatively fragile structures built atop its outermost layer. Our understanding of the seismic hazard (i.e., the potential for earthquakes and related effects) has improved significantly in the last two decades, largely through research supported by the National Earthquake Hazards Reduction Program (NEHRP). This improved knowledge of the seismic hazard can in turn be applied to better estimation of the potential impact on specific communities. For example, earthquake-related research and development (R&D) to date has yielded detailed information on historical and estimated future ground motions that earthquake engineers now use for research, design, and building code development.

Federal support for earthquake-related R&D in the earth sciences is concentrated in programs directed by both the National Science Foundation and the U.S. Geological Survey (USGS) under the aegis of NEHRP; other federal agencies conduct related research as well (see appendix B). Since focused efforts began, there have been many achievements in earth sciences. However, the complexity of the task of understanding earthquake phenomena means that significant uncertainties remain about the timing and location of future damaging earthquakes and the exact nature of their effects.

This chapter reviews the current knowledge of earthquake phenomena and of seismic hazards across the United States. It then outlines the role of basic and applied earth science R&D in meeting information needs for the nation's earthquake loss mitigation program, and provides examples of research efforts needed to address knowledge gaps.

EARTHQUAKES

An "earthquake" technically refers to trembling or strong ground shaking caused by the passage of seismic waves through the earth's rocky interior. These waves arise from phenomena as varied as explosions,[1] volcanic eruptions, or quarry blasts, but the source most commonly associated with the term is the fracturing, or *faulting*, of rocks deep underground through the action of powerful geologic forces.

Seismic waves radiate away from a rupturing fault in the same way that ripples in a pond spread outward from a splashing pebble. These waves die away with distance from the initial source, so that very distant or very deep earthquakes are of relatively little concern. Like pond ripples, the waves can bounce and bend around obstacles to produce intricate patterns. Because the structure of the earth is far more complicated than the surface of a pond, what happens when seismic waves reach the earth's surface can be exceedingly complex.

Efforts to assess risks to U.S. communities posed by future earthquakes rest on the ability to estimate where and when earthquakes will occur and to quantify, where possible, what will happen when earthquake-generated seismic waves hit the earth's surface. (Figure 2-1 illustrates seismicity that has occurred in the United States.) Specific questions addressed by current earth science research include:

- What causes a particular fault to rupture?
- How do seismic waves propagate through the earth?
- How do seismic waves and local geology interact to produce strong ground motions[2] or damage to the earth's surface?

Two distinct methods of evaluating the severity of an earthquake are: 1) calculating its *magnitude*, and 2) estimating its *intensity*. The magnitude of an earthquake is related to the amount of seismic energy released at the quake's source; it is based on the amplitude of the seismic waves recorded on seismographs. Earthquake magnitude calculations also take into account the effects of distance between the recording instrument and the source of the waves, and the type of instrument itself.[3]

The magnitude scale most widely used for many years is the Richter magnitude scale, introduced in 1935 by Charles Richter and Beno Gutenberg. A strong earthquake, for example, would have a Richter magnitude (M) of 6.0 to 7.0, while a great earthquake such as the 1906 earthquake beneath San Francisco would measure above M8. Although it is open-ended, the Richter scale does not accurately measure large earthquakes on faults with a great rupture length.[4] To better quantify the severity of great quakes, scientists have developed the moment magnitude scale. The moment magnitude (Mw) measures the total seismic energy released, which is a function of rock rigidity in the fault, the area of rupture on the fault plane, and the amount of slip. These scales are compared in table 2-1.

In contrast to magnitude, an earthquake's *intensity* is a highly subjective measure. For many years the Modified Mercalli Intensity (MMI) scale, developed in 1931, has been used to describe the relative strength of ground shaking experienced at a particular location. Seismologists assign intensity using the 12-increment scale that reflects the effects of shaking on people, damage to the built environment, and changes in the natu-

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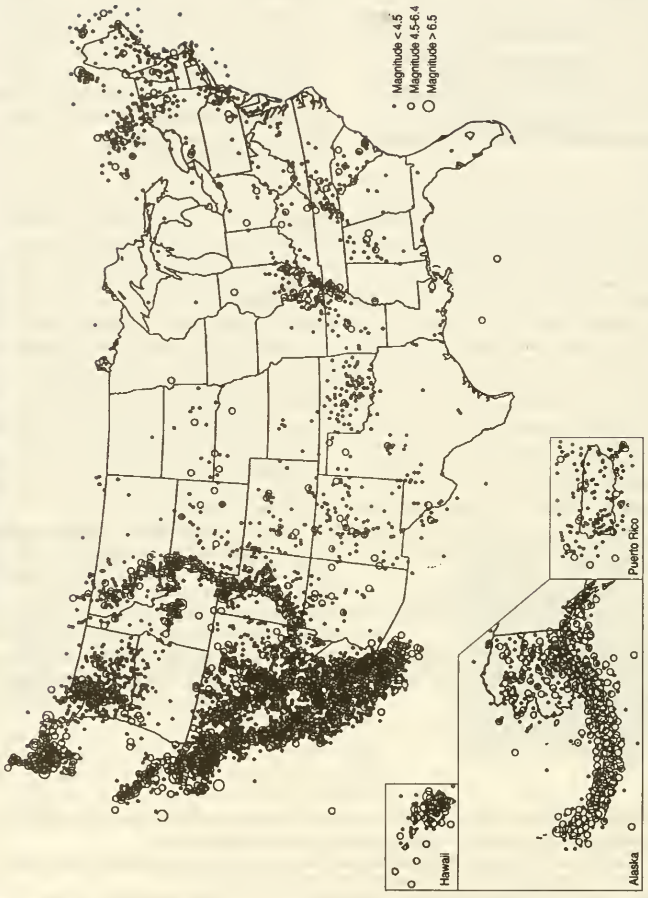
[1] Nuclear explosions, for example, generate seismic waves that can be detected at great distances by earthquake-monitoring networks.

[2] Strong motions are energetic ground displacements that cause damage to buildings and other structures.

[3] U.S. Geological Survey, "The Severity of an Earthquake," brochure, 1990. This report adopts the classification for quakes of different strengths as follows (M=magnitude): moderate, M5-6; strong, M6-7; major, M7-8; and great, M>8.

[4] Much of the energy of a large earthquake is transmitted via long-wavelength seismic waves, the frequency of which is too low to factor into calculations of earthquake magnitude.

FIGURE 2-1: Seismicity of the United States, 1899-1990



SOURCE: U.S. Geological Survey, National Earthquake Information Center.

TABLE 2-1: Comparison of Richter and Moment Magnitudes for Selected Quakes

Earthquake	Richter magnitude	Moment magnitude
Chile, 1960	8.3	9 5
Alaska, 1964	8 4	9 2
New Madnd, Missouri, 1812	8.7	8 1
Mexico, 1985	8 1	8 1
San Francisco, California, 1906	8.3	7 7
Loma Prieta, California, 1989	7.1	7 0
Kobe, Japan, 1995	6 8	6 9
San Fernando, California, 1971	6 4	6.7
Northridge, California, 1994	6 4	6.7

SOURCE: Rick Gore, "Living with California's Faults," *National Geographic*, vol 187, No 4, April 1995, p 10

ral environment.[5] Table 2-2 provides an abbreviated description of the MMI scale.

Continuing research has illuminated both the basic setting for earthquakes and their hazardous effects. These two topics set the stage for understanding the seismic hazards that exist in different areas of the country.

Geologic Setting for Earthquakes

The overall framework that guides the discussion of earthquake occurrence is the theory of plate tectonics, a large-scale picture of the earth's basic workings originally set forth in the 1960s and 1970s.[6] In this conceptual framework, the rocks making up the outer layers of the earth are broken into a patchwork of ever-shifting tectonic plates (see figure 2-2). Some of these plates are enormous—the rocks underlying much of the Pacific Ocean, for example, lie on a single 10,000-km-wide Pacific Plate—whereas others may span only a few hundred kilometers. What distinguishes a plate, however, is that it moves as a cohesive body across the surface of the earth.[7] As a plate moves, it grinds or knocks against its neighbors; this plate-to-plate interaction produces the majority of the world's earthquakes.

With a few significant exceptions, identifying the most likely breeding ground for damaging earthquakes is thus synonymous with finding the boundaries of tectonic plates. The two types of plate boundaries associated with damaging earthquakes in the United States are subduction zones and strike-slip faults. In addition, there are intraplate earthquakes, whose origins are less well understood[8] (see box 2-1).

Earthquake Effects at the Earth's Surface

Besides knowing where and when earthquakes might occur, those interested in reducing earth-

[5] "Quake Intensity," *Earthquakes and Volcanoes*, vol. 24, No. 1, 1993, p. 42.

[6] It should be noted that many of the data that supported the theory's development were derived from pre-NEHRP efforts (e.g., Department of Defense mapping of seafloors, and global seismic monitoring aimed at detecting nuclear testing in the former Soviet Union).

[7] This motion is slow—usually on the order of a few centimeters or less per year. Over millions of years, however, it can carry continents from the equator to the poles, rip landmasses apart, or assemble disconnected land fragments into continents.

[8] Intraplate quakes, which can strike deep within a plate's interior, are relatively rare. There are also earthquakes associated with mountain-building and active continental deformation far inland from plate boundaries. One theory is that such activity in western states reflects the presence of a diffuse plate boundary stretching from the Pacific coast to the front ranges of Utah, in which case earthquakes in the Intermountain West are not "intraplate" quakes at all. This report adopts the convention that the North American Plate ends near the Pacific coast and that earthquakes in the Intermountain West are intraplate events.

TABLE 2-2: Modified Mercalli Intensity Scale and Corresponding Effects

MMI	Description
I	Not felt except by a very few under especially favorable circumstances.
II	Felt only by a few persons at rest, especially on upper floors of buildings.
III	Felt quite noticeably indoors, especially on upper floors of buildings
IV	During the day, felt indoors by many, outdoors by few At night, some awakened
V	Felt by nearly everyone; many awakened. Some dishes windows broken; a few instances of cracked plaster; unstable objects overturned.
VI	Felt by all; many frightened and run outdoors Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys Damage slight
VII	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures. Some chimneys broken.
VIII	Damage slight in specially designed structures, considerable in ordinary substantial buildings, with partial collapse; great in poorly built structures. Chimneys, factory stacks, columns, monuments, and walls fall.
IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; damage great in substantial buildings.
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent
XI	Few masonry structures remain standing Bridges destroyed
XII	Damage total Lines of sight and level distorted. Objects thrown upward into the air.

SOURCE U S Geological Survey, "The Severity of an Earthquake," brochure, 1990.

quake losses are concerned with what effects an earthquake might have on nearby communities. Earthquake engineers, for example, desire quantitative assessments of expected ground motion or deformation in order to evaluate the likely impact on buildings or lifelines.[9]

Ground Shaking

Contrary to the popular image in Hollywood movies or the more spectacular literary accounts, the earth generally does not open up and swallow buildings during earthquakes. Cracks and fissures do occasionally break the earth's surface. However, they are secondary effects of the most damaging earthquake phenomenon—strong ground shaking caused by seismic waves.

Analogous to sound waves,[10] seismic waves can be produced at different frequencies (corresponding to the pitch of a musical note) and at different amplitudes (corresponding to volume). Large earthquakes (which involve big motions on big faults) tend to produce larger amplitude, lower frequency waves. In reality, however, all earthquakes produce a complex suite of different waves of varying amplitudes and frequencies.

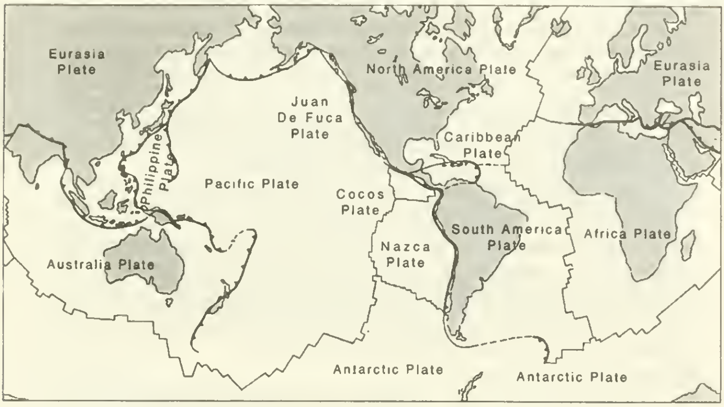
The damage done to structures and their contents depends on the characteristics of the ground motion. The shaking may be up and down, side to side, or some complex combination of the two. There may be a short flurry of rapid, energetic motions followed by rolling or swaying motions that last several seconds or more. Higher frequency accelerations[11] primarily affect shorter, stiffer structures; repetitive, lower frequency motions pose a special threat to very tall or flexible structures. Displacements produced by very large amplitude

[9] *Lifelines* are roads, bridges, communication systems, utilities, and other essential infrastructure. See chapter 3.

[10] One type of seismic wave, the *P-wave*, is in fact an underground sound wave.

[11] Acceleration is commonly expressed as a fraction of the strength of earth's gravity, *g*. A vertical acceleration of more than 1 g can actually throw objects in the air.

FIGURE 2-2: World's Major Tectonic Plates



SOURCE: Office of Technology Assessment, 1995, based on Bruce A. Bolt, *Earthquakes* (New York, NY: W.H. Freeman and Co., 1993), p. 36

waves can stretch or twist structures beyond their engineering limits. The frequency, energy content, and duration of shaking are not related simply to earthquake size, but also to distance from the fault, direction of rupture, and local geology, including soil conditions.

Increasingly, earth scientists have applied state-of-the-art R&D to determining what sort of ground acceleration and displacement is to be expected in different earthquake regions. Such estimates require knowledge (or prediction) of what waves are originally generated by the earthquake (which implies an understanding of exactly how earthquakes occur) and of how these waves decay, grow, or combine as they travel through the earth. The latter requires geophysical and geological mapping of the rocks between the earthquake and the area of concern.

Because softer soils and clay tend to amplify ground motions, compared with those experienced on bedrock, research has also been directed at how seismic waves interact with surficial and near-surface materials to enhance ground shaking. A dramatic example of the effects of localized geology was the 1985 Mexico City earthquake; ground motions there were significantly enhanced at periods of several seconds compared with those at hard-rock sites closer to the quake source[12] (see box 2-2).

[12] Thomas H. Heaton and Stephen H. Hartzell, "Earthquake Ground Motions," *Annual Review of Earth Planetary Science*, vol. 16, 1988, p. 124.

BOX 2-1: Geologic Settings for Earthquakes

Subduction Zones

In Alaska and the Pacific Northwest, the overriding of the North American continent over the various plates of the Pacific Ocean has led to the formation of *subduction zones*, a type of plate boundary that generally produces very large earthquakes. In a subduction zone, the layers of rock making up an oceanic plate move toward a landmass and, in the resulting collision, are forced down into the earth's deep interior. In the Pacific Northwest, this collision is responsible for the presence of the region's coastal mountains, for the volcanic activity that has produced the Cascade Mountain Range, and—most significantly—for the potential for major earthquakes to occur where the subducting plate is stuck, or locked, against the overriding continent. In most cases, this is at depths of 15 to 45 km (10 to 30 miles).

Earthquakes in subduction zones generally reflect the presence of *thrust faults*—fractures in the earth that allow one rock mass to slide toward and over its neighbor. The seismic waves thus generated shake the ground upward and downward as well as forward and back. Because the faults allow for vertical motions, subduction zone earthquakes can lead to the uplift or subsidence of local landmasses, over time flooding coastal areas or leaving them high and dry. If the earthquake occurs offshore beneath the ocean (the plate boundary in a subduction zone generally lies underwater and out of sight), the vertical motion of the sea bottom can send a surge of water (a *tsunami*) racing toward vulnerable seaside communities. Finally, since subduction zones are typically mountainous (because of all the vertical fault motion), strong subduction temblors can set off major landslides, avalanches, or mudflow.

Strike-Slip Plate Boundaries

A very different type of plate interaction is at work in California and southeast Alaska. Here, the Pacific Plate (on which Baja California and the westernmost sliver of the North American continent rest) slides sideways against the North American Plate in a motion known geologically as *strike-slip*. On a strike-slip boundary, there is very little up-and-down motion, most earthquake waves are side to side, and seismic activity does not raise mountains or produce tsunamis in the way it does in a subduction zone.

In the case of California, the seam between the North American and Pacific Plates is the San Andreas fault, a long and distinct scar in the earth's surface that runs beneath San Francisco, through central California, and southward toward Mexico through the desert east of Los Angeles.[1] There is another strike-slip plate boundary fault off the coast of southeast Alaska. Earthquakes occur along these faults primarily because relative motion, or *slip*, along either fault is not continuous over time or distance. That is, the fault is locked most of time, so that no slip occurs. The inexorable movement of the tectonic plates, however, causes stress to build along the fault until, for poorly understood reasons, one or more segments of the fault rupture, releasing the stored-up energy in an earthquake.

In California, most of the slip between the North American and Pacific Plates occurs along the San Andreas fault or in the immediate vicinity. Some deformation of the plate edges also occurs many miles from the primary fault, leading to stress-relieving earthquakes on strike-slip faults located on either side of the San Andreas. An example is the 1992 Landers earthquake (M7.3). The largest U.S. earthquake in 40 years, it occurred in a relatively sparsely populated area several miles northeast of Los Angeles.

[1] A continuous narrow break in the earth's crust, the entire fault zone is more than 800 miles long and extends at least 16 km beneath the earth's surface. Sandra E. Schulz and Robert E. Wallace, *The San Andreas Fault*, prepared for the U.S. Geological Survey (Washington, DC: U.S. Government Printing Office, 1993), pp. 3-4.

(continued)

BOX 2-1 (cont'd.): Geologic Settings for Earthquakes

A pronounced bend in the San Andreas north of the Los Angeles area effectively locks the motion of the tectonic plates, contributing to vertical deformation and setting the stage for earthquakes on downward-dipping faults hidden from view beneath the earth's surface. The 1971 San Fernando and 1994 Northridge quakes both ruptured such "blind" thrust faults

Intraplate Earthquakes

Although more than 90 percent of the world's earthquakes occur on plate boundaries, damaging earthquakes have also occurred in areas far from plate edges. *Intraplate* earthquakes, which though uncommon can be sizable, seem to reflect processes that are a topic of current tectonic and geophysical research Possible explanations include 1) dynamic interactions between the earth's stiff exterior layers and its deeper, more flowing mantle; 2) a continent's adjusting to evolving plate boundary geometries (the Basin and Range Province of Nevada, for example, is stretching east-west following the disappearance of a subduction zone that once lay to the west); or 3) the interaction between zones of weakness within a plate and stresses transmitted across the plate from its boundaries.

The regions of the United States in which future intraplate earthquakes are most likely to occur are the Intermountain West and central United States, although parts of the Atlantic seaboard are also susceptible [2] Compared with interplate earthquakes, uncertainty over the origin, likelihood, severity, and characteristics of intraplate quakes is very high Improved understanding can come only through further basic earth science research

[2] The eastern coast of North America, while marking the edge of the continent, is not a plate boundary, North America is joined directly to the rocks underlying the western half of the Atlantic Ocean, and the eastern boundary of the North American Plate lies in the middle of the Atlantic

SOURCE Office of Technology Assessment, 1995

Other Effects

The shaking caused by seismic waves, in addition to directly damaging structures, can also affect the earth's surface in ways equally detrimental (or more so) to the built environment. Ground failure, as these effects are often called, has several different facets:

- liquefaction, whereby shaking transforms a water-saturated soil or sediment into a thick, quicksand-like slurry;
- ground rupture, in which shaking opens up fissures and cracks in the soil;
- surface faulting, in which an earthquake fault reaches the surface of the earth and produces vertical or horizontal *offsets* of material astride the fault;
- landslides or avalanches; and
- damaging water waves (e.g., tsunamis and seiches).[13]

[13] Fast-moving surges of water that travel across the ocean, *tsunamis* form a steep wall of water when entering shallow water along shorelines. The local wave height and run-up length are affected by the topography of the seafloor and continental shelf and by the shape of the shoreline—tsunamis with crests as high as 25 meters have devastated parts of Japan. Bruce A. Bolt, *Earthquakes* (New York, NY. W.H. Freeman and Co., 1993), pp. 148, 151. Tsunami generation is not fully understood, and may result more from the absolute motion of material at an earthquake fault than from the ground shaking from seismic waves. *Seiches* are earthquake-generated surges of water on lakes and enclosed bays.

BOX 2-2: Mexico City Earthquake

On September 19, 1985, Mexico City experienced the effects of an M8.1 quake that occurred in a subduction zone 350 km away Strong shaking caused extensive damage, killed thousands of people,[1] and left many more thousands homeless Most of the damage was confined to areas of the city built on soft, water-saturated soils

Key factors in the devastating losses included

- the long duration of shaking,
- local soil conditions that amplified seismic energy and produced extensive liquefaction;
- poor overall configuration and significant irregularities in the distribution of buildings mass, strength, and stiffness, and
- poor quality control of building materials

Rupture on the segment of a subduction zone known as the Michoacán gap produced approximately 1 5 minutes of shaking with a roughly two-second period (Higher frequency motions were damped over the distance between the earthquake's focus and Mexico City)

Liquefaction was widespread, and soil-structure interaction increased the structural response of many multistory buildings to a period that coincided with the long-period motion produced by the quake. The effects of this resonance included drift, deformation, and pounding between buildings

[1] The official count is 4,596 lives lost, although other estimates are as high as 20,000

SOURCE Applied Technology Council and Earthquake Engineering Research Institute, *Proceedings of the Workshop for Utilization of Research on Engineering and Socioeconomic Aspects of the 1985 Chile and Mexico Earthquakes*, ATC-30 (Redwood City, CA Applied Technology Council), 1991

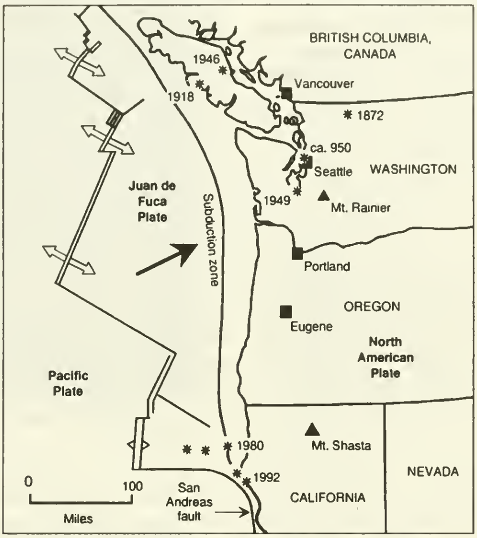
Like strong ground shaking, ground failure is strongly dependent on the surface and near-surface geology. Areas adjacent to waterways and developed with artificial fill are particularly susceptible to liquefaction, as seen in the Marina district in San Francisco during the 1989 Loma Prieta earthquake and in the 1995 Hyogoken-Nanbu earthquake that struck Kobe, Japan. Lateral spreading (in which surface layers are transported laterally over liquefied soils) ruptured water and sewer lines in the Kobe quake. The shaking produced by the 1994 Northridge, California, quake and its aftershocks caused thousands of landslides in nearby mountains.

SEISMIC HAZARDS ACROSS THE UNITED STATES

Earthquake researchers use an understanding of the basic setting for earthquakes and knowledge of prior earthquakes to assess seismic hazards and relate these to affected communities. Earthquake hazards vary widely across the country, from high in Alaska and the West Coast to low (but not zero) in much of the eastern United States. There is a continuum of earthquake risk,[14] as well: where heavy urbanization exists and frequent damaging earthquakes are expected, the risk is very high (e.g., in the San Francisco Bay or Los Angeles

[14] *Seismic hazard* is the potential for an earthquake and related effects to occur. *Seismic risk* is the likelihood for casualties, damage to the built environment, or other losses to occur as a result of earthquakes.

FIGURE 2-3: Tectonic Setting and Significant Earthquakes in the Pacific Northwest



NOTE. * indicates earthquakes of magnitude greater than 7

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

areas). In the Pacific Northwest, the seismic risk stems from the potential for infrequent but large to great earthquakes and from the region's status as a relative newcomer to mitigation (i.e., fewer steps have been taken to reduce risk). Likewise, central and eastern areas of the United States face the threat of significant earthquakes over very long intervals; the low frequency of damaging seismic events in recent history has contributed to the more limited implementation of mitigation measures than in the West, despite the vulnerability of many population centers (e.g., New York City or Boston) to even moderate shaking. The following sections describe current knowledge of earthquake hazards in different regions of the United States.

Pacific Northwest

The coastal area stretching from Alaska's western Aleutian Islands to the states of Washington and Oregon is at risk for both moderate and enormously powerful earthquakes. This area encompasses the growing metropolitan areas of Seattle, Portland, and Anchorage, as well as cities on Canada's west coast. Estimates of possible earthquake magnitudes in the region range as high as magnitude 9 (see figure 2-3).

The convergence of tectonic plates creates a high likelihood of seismic activity. For this reason, Alaska frequently experiences potentially damaging earthquakes, but due to its relatively low population density the impact is smaller than in more developed areas. In 1964, the second largest quake of this century struck Alaska, uplifting sections of the ocean floor and causing extensive damage to the Anchorage area. The Mw9.2 quake also caused a tsunami that led to further loss of life and damage in Alaska and in the northern California coastal town of Crescent City.

If such a temblor occurred further south, it could affect coastal communities from Vancouver, British Columbia, to northern California. However, off the coasts of Oregon and Washington, there have been no quakes of this size during recorded history. Awareness of this particular seismic threat was low until evidence of tsunami deposits and changes in coastal elevation, gathered in large part through NEHRP, revealed that great subduction zone earthquakes had occurred in the past. Based on tsunami records from Japan, the most recent may have been in the year 1700.[15]

Moderate-to-large crustal earthquakes in Oregon and Washington have been relatively infrequent, but the risk to population centers is significant. A major quake struck the Cascades of northern Washington in 1872;[16] the Puget Sound region experienced quakes of magnitudes 7.1 and 6.5 in this century;[17] and as recently as March 1993, a M5.6 temblor rocked the Oregon capital city of Salem.[18]

Uncertainty remains over how likely or how severe future events may be. Research into this question, much of it involving the modeling of geophysical processes in the region, is active and growing, and may eventually remove much of this uncertainty. In the meantime, complementary research into paleoseismology (the study of early historic or prehistoric earthquake activity based on geologic evidence) seeks to refine estimates of the timing and magnitude of previous subduction zone and crustal quakes. Besides indicating that prehistoric, devastating tsunamis occurred, the geologic record also suggests that a major earthquake took place 1,100 years ago directly beneath what is now downtown Seattle.[19]

California

A combination of high population density, heavy levels of urbanization, and the relatively frequent occurrence of moderate to great earthquakes makes California a state with very high seismic risk. Other areas in the United States may experience equally severe earthquake disasters, but the likelihood is lower.

For many years it was thought that the earthquake hazard in California stemmed primarily from the great San Andreas fault system, which accommodates the sliding of the North American continent sideways against the Pacific Plate. Several M8+ earthquakes have occurred along the San Andreas, including the great 1906 San Francisco Earthquake. The long-awaited "Big One" is ex-

[15] Kenji Satake et al., "A Possible Cascadia Earthquake of January 26, 1700, as Inferred from Tsunami Records in Japan," *Geological Society of America 1995 Abstracts with Programs*, vol. 27, No. 5, 1995, p. 76.

[16] Reported effects indicate that its magnitude was approximately 7.4, probably the largest during recorded history for that area. Thomas Yelin et al., *Washington and Oregon Earthquake History and Hazards*, U.S. Geological Survey Open File Report 94-226B (Denver, CO: National Earthquake Information Center, 1994), p. 7.

[17] The quakes took place in 1949 (M7.1) and 1965 (M6.5); both deep quakes (depths of 54 to 63 km), they caused several deaths and significant damage. Linda Lawrance Noson et al., *Washington State Earthquake Hazards*, Information Circular 85 (Olympia, WA: Washington Department of Natural Resources, 1988), p. 21.

[18] Six months later, a pair of strong quakes occurred a little more than two hours apart near Klamath Falls, in the southern part of the state. Shallow crustal quakes like these have also occurred in the Portland area. Yelin et al., see footnote 16.

[19] Ibid., p. 9.

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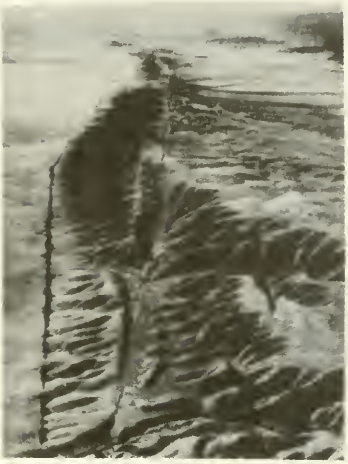


Looking northwest along the San Andreas fault, the seam between the North American and Pacific Plates, in the Carrizo Plain (central California)

pected to involve rupture of the fault's southern section.

A more recently recognized danger is the likelihood of future moderate-to-large earthquakes occurring on lesser known or even unsuspected faults adjacent to or directly underneath major metropolitan centers (see figure 2-4). The quake beneath Northridge in January 1994 revealed all too well the hazardous potential of blind thrust faults in the Los Angeles area.[20]

The danger of these blind thrust systems is a combination of the size of their associated earthquakes and their proximity to urban centers. Because an earthquake's damaging effects tend to decrease rapidly with distance, the physical separation between the San Andreas and a metropolitan center such as Los Angeles allows policymakers to prepare the built environment against a lesser amount of damage than sheer earthquake magnitude might seem to warrant. However, if a fault capable of producing earthquakes is close by, then its proximity allows even a moderate event to inflict more damage than might result from the long-awaited "Big One."[21]

In northern California, the geometric complexity of the San Andreas fault system that prevents North America from sliding cleanly against the Pacific Plate causes the San Andreas to branch off into a series of smaller faults that run in a north-south direction along the east side of San Francisco Bay (see figure 2-5). In addition to the 1906 San Francisco and 1989 Loma Prieta earthquakes, the Bay Area has experienced 20 other moderate to great earthquakes in the last 160 years.[22]

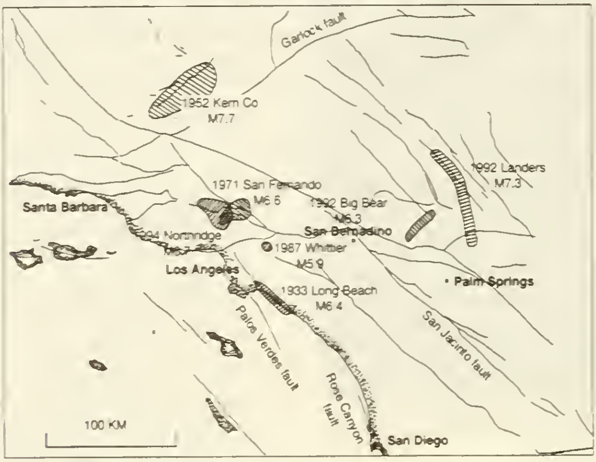
Because of these and other findings from recent research, the true earthquake hazard in California remains uncertain, and future estimates may well be subject to upgrading. As of 1990, **the estimated likelihood of major (M7+) earthquakes stands at 67 percent over 30 years in the San**

[20] Seismograph and strong-motion instrument data recorded during and after the Northridge earthquake indicate larger ground motions than have typically been observed or reflected in engineering design in California. The aftermath of the quake included realization that improved knowledge of the system of blind thrust faults lying beneath the Los Angeles area and environs would be useful for targeting mitigation efforts. While oil company studies are a good source of information about subsurface structure, the mapping rarely extends to depths where earthquakes initiate.

[21] It appears that one such fault, the Elysian Park blind thrust fault, lies directly beneath downtown Los Angeles.

[22] Association of Bay Area Governments, "The Bay Area Is Earthquake Country," Internet, address http://www.abag.ca.gov/bayarea/eqmaps/doc/text1.html#background, citing Jeanne B. Perkins and John Boatwright, *The San Francisco Bay Area—On Shaky Ground* (Oakland, CA: Association of Bay Area Governments, April 1995).

FIGURE 2-4: Earthquake Source Zones for Selected Significant Events in Southern California



NOTE: Shaded areas represent rupture zones for earthquakes shown.

SOURCE: U.S. Geological Survey 1995.

Francisco Bay area.[23] Studies of the potential for liquefaction and ground failure that would result from shaking on the San Andreas and its neighbors across the Bay are continuing,[24] as are investigations of local fault structures.

The 30-year probability of a major earthquake in southern California, estimated in 1994, is 80 to 90 percent (this estimate reflects both San Andreas and blind thrust hazards for the urban corridor from San Bernardino through Los Angeles to Santa Barbara).[25] Scientists have also noticed a historical deficit in the size or number of earthquakes expected for southern California;

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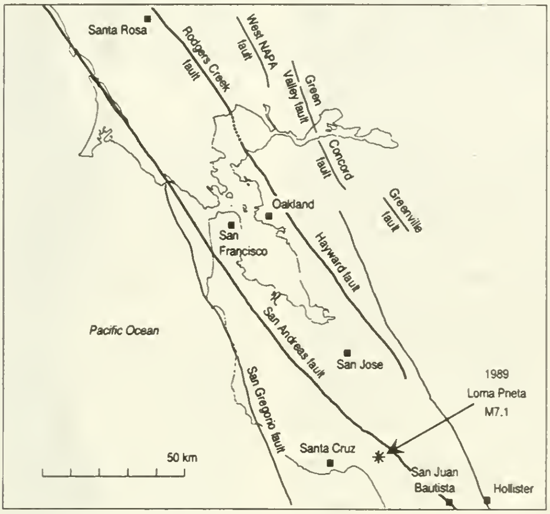
[23] The primary fault structures evaluated for the assessment were nearby segments of the San Andreas fault and the neighboring fault system east of the bay, which consists of the Hayward and Rodgers Creek faults. Working Group on California Earthquake Probabilities, *Probabilities of Large Earthquakes in the San Francisco Bay Region, California*, U.S. Geological Survey Circular 1053 (Washington, DC: U.S. Government Printing Office, 1990), p. 31.

[24] This is an area of cooperation between USGS and the California Division of Mines and Geology, the state agency responsible for mapping special hazard zones.

[25] 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; USGS and SCEC Scientists, "The Magnitude 6.7 Northridge, California, Earthquake of 17 January 1994," *Science*, vol. 266, Oct. 21, 1994, p. 396.

FIGURE 2-5: Primary Faults in the San Francisco Bay Area



SOURCE: U.S. Geological Survey, 1995

geologic and geodetic data indicate that too few earthquakes have occurred to account for strain accumulation.[26] Whether this points to bigger quakes or to more frequent quakes is still under discussion in the scientific community.

Intermountain Seismic Belt

A region not commonly associated with seismic hazards—yet nevertheless under considerable risk—is the Intermountain Seismic Belt. Stretching from southern Idaho and western Montana down through southwestern Utah and Nevada, this area includes the urban center of Salt Lake City, Utah, and other rapidly growing communities in the Intermountain West (e.g., Boise, Idaho, and Reno, Nevada).

Earthquakes here do not stem from the plate collisional processes of the Pacific Northwest or from the sideways sliding of adjacent plates seen in California. Rather, they arise from intraplate deformation of the North American continent associated with the uplift of the Rocky Mountains

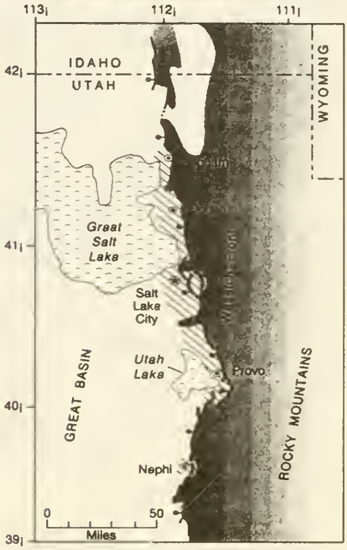
[26] James F. Dolan et al., "Prospects for Larger or More Frequent Earthquakes in the Los Angeles Metropolitan Area," *Science*, vol. 267, Jan. 13, 1995, p. 203; and Working Group on California Earthquake Probabilities, see footnote 25.

and the east-west stretching of the Basin and Range Province. Because this region lies within the interior of the North American Plate and far from the active deformation, collision, and sliding experienced at the plate edges, damaging earthquakes are relatively rare. However, since these earthquakes reflect active mountain-building processes in the continental interior, when they do occur, they can be sizable (M7 or higher).

Even though the maximum earthquake magnitudes in this region appear to be less severe than those projected or observed in the Pacific Northwest or California, the potential for disaster exists simply because the scarcity of historic earthquakes has led to a relatively low level of preparedness. General settlement of the area did not begin until the 1840s; in the intervening years, there have been no large quakes near the region's few urban centers. Consequently, damaging earthquakes have generally been less of a public concern than is the case in California. The region's last major quakes were in Montana in 1959, when several people were killed by landslides, and southern Idaho in 1983.

Awareness of the threat to Utah's metropolitan corridor grew as a result of a major NEHRP project to study the Wasatch Front, which is formed by the uplift of the Rocky Mountains along a long, north-south fault zone—the Wasatch fault zone (see figure 2-6). The research showed that major earthquakes *have* occurred in the past, with paleoseismic evidence suggesting a roughly 400-year recurrence along the most urbanized part of the Wasatch fault zone.[27] In 1991, **the probability of a M7+ earthquake anywhere along the Wasatch was estimated to be 13 percent over a 50-year period.**[28] An earthquake of that size anywhere along the fault zone will be felt throughout the system, and is likely to damage structures in the closest cities.[29]

FIGURE 2-6: Wasatch Fault Zone



NOTE: Thick line designates the Wasatch fault. About 80 percent of Utah's population, or nearly 1.6 million people, are at risk to movement of the fault.

SOURCE: U.S. Geological Survey, 1995.

Although a major earthquake in a California city would cause considerable damage and loss of life, an occurrence in less-prepared Utah could be

[27] Michael N. Machette et al., "Paleoseismology of the Wasatch Fault Zone: A Summary of Recent Investigations, Interpretations, and Conclusions," USGS Professional Paper 1500-A, November 1990, p. A55. Led by USGS and the Utah Geological and Mineral Survey, the project was completed in the early 1990s; seismic hazard and risk assessment continues today under state and local authorities.

[28] S. Nishenko, "Probabilistic Estimates for the Wasatch Fault," in *Proceedings of the National Earthquake Prediction Evaluation Council*, June 11-12, 1991, Alta, Utah, USGS Open File Report 92-249 (Washington, DC: U.S. Geological Survey, 1992), pp. 16-19.

[29] Kaye Shedlock, U.S. Geological Survey, Earthquake and Landslide Hazards Branch, personal communication, Apr. 15, 1995.

far worse.[30] Moreover, continued population growth in the region will likely lead to urbanization in areas relatively untargeted (until recently) by earthquake researchers; this raises the possibility of additional damage in areas currently unaware of their seismic hazard.

Central United States

A series of three great earthquakes occurred between December 1811 and February 1812 near New Madrid, Missouri, opening chasms in the earth, destroying the scattered settlements in the region, and causing sections of the Mississippi River to temporarily reverse and flow backward. Although there were no modern seismographic instruments available then to record the quakes' magnitudes, the level of destruction witnessed places these events among the most powerful ever.[31]

The challenge to the earth science community has therefore been to determine the likelihood of future damaging earthquakes in this region, and to decide whether the great New Madrid earthquakes were a geophysical fluke or the offspring of geologic conditions specific to the region.[32] In many respects, this task has been more difficult to perform than is generally the case in the western United States, because earthquakes in the central and eastern United States cannot be accounted for by classic plate tectonic theory. Compounding this difficulty is an observational problem caused by the presence of the Mississippi. Sediments carried by the river and deposited overland during floods over the eons have blanketed the region with kilometers of mud, sand, clay, and soil that effectively hide potential earthquake faults from view.[33]

About a decade ago, a major success was achieved in the identification of a geologic structure that appears tied to the region's earthquakes. This structure, the Reelfoot Rift, is a buried series of faults and anomalous rock formations formed 500 million years ago when tectonic forces tried but failed to split North America in two.[34] The rifting event in effect drew a wounding scar through the more-or-less contiguous landmass of the central and eastern United States. It is this singular zone of weakness (identified through geophysical surveys) that may account for the New Madrid earthquakes (see figure 2-7).

Thus, it appears that seismicity in this area is tied to a particular geologic structure, and is not expected to recur randomly elsewhere (see figure 2-7). However, scientists have also learned that any earthquakes that do occur in the eastern half of the United States will be felt far more widely than

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[30] A 1976 USGS study, for example, projected 14,000 fatalities in the event of a major Wasatch Front event The Salt Lake area has since upgraded its seismic zone status and implemented hazard assessment and mitigation projects.

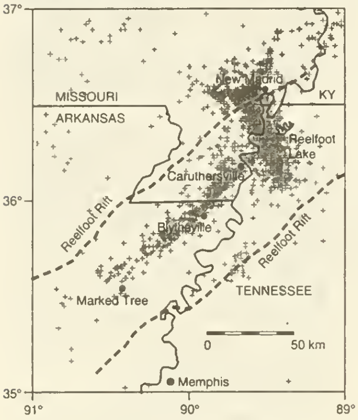
[31] With MMI of XI and XII, these temblors were the largest to occur within the coterminous United States; the 1812 quake was felt throughout an area of 5 million square kilometers. For comparison, the great San Francisco earthquake of 1906 had an MMI of XI and registered 8.3 the Richter scale. William Atkinson, *The Next New Madrid Earthquake: A Survival Guide for the Midwest* (Carbondale and Edwardsville, IL: Southern Illinois University Press, 1989), p. 22; and Bolt, see footnote 13, pp. 5, 270, 277.

[32] The former conclusion would suggest that a repeat might occur virtually anywhere in the United States; the latter, although disquieting to local residents, at least confines the likely region of future devastation.

[33] Although the deep sedimentary cap precludes direct observation of the faults, sedimentation facilitates paleoseismic work, and some information about the region's tectonic structures can be inferred by its topography. Geologic evidence indicates that three large earthquakes have occurred in the New Madrid area over the last 2,400 years, a recurrence rate comparable to that for the Wasatch fault or many reverse faults in California. Robert Yeats, Department of Geosciences, Oregon State University, personal communication, May 7, 1995; and see Keith I. Kelson et al., "Multiple Late Holocene Earthquakes Along the Reelfoot Fault, Central New Madrid Seismic Zone," *Journal of Geophysical Research*, forthcoming, January 1996.

[34] Robert M. Hamilton and Arch C. Johnston (eds.), *Tecumseh's Prophecy: Preparing for the Next New Madrid Earthquake*, U.S. Geological Survey Circular 1066 (Washington, DC: U.S. Government Printing Office, 1990), p. 9. At the time, North America was joined to Eurasia and Africa. Following the failure of the Reelfoot Rift, the landmass farther east split to form the proto-Atlantic Ocean.

FIGURE 2-7: New Madrid Seismic Zone



NOTE Shaded area shows region of intense liquefaction in 1811 to 1812 earthquakes, small hatches represent seismicity during 1974 to 1991, and heavy dashed lines indicate boundaries of the Reelfoot Rift

SOURCE U.S Geological Survey, 1995

quakes that occur west of the Rockies (see box 2-3).

Given the potentially far-flung and devastating effects of a major earthquake in the central United States, it is critical that earthquake severity and timing estimates are refined to the point that regional policymakers know the need and time scale for action. Unfortunately, uncertainties for the region remain substantial. Although the presence of the Reelfoot Rift provides an explanation for the siting of earthquakes, it does not by itself predict their occurrence. At present, there is no clear consensus on what mechanism causes tectonic stress in the region to build up to the point of an earthquake. In the absence of a conceptual tectonic model, the best guide to future earthquake activity in this region lies in the record of past earthquakes. This record suggests a recurrence of moderate quakes every 60 to 90 years (the last moderate event was in 1895).[35] **The probability of an M6.3 quake before 2040 is 86 to 97 percent; of an M8.3 quake, 2.7 to 4 percent.**[36]

Furthermore, outside the immediate New Madrid Seismic Zone, the characteristics of the source zones in the central (and eastern) United States are poorly known. The region is virtually devoid of identifiable active faulting,[37] and geologic studies of seismogenic features are in the reconnaissance stage. Although current levels of seismicity indicate a low hazard, NEHRP-supported studies have provided evidence of several major quakes in the Wabash Valley area (southern Indiana and Illinois) over the last 20,000 years.

Eastern United States

The Pacific Northwest, California, Intermountain West, and central United States have constituted the primary earthquake concerns in this country because the likelihood and potentially devastating effects of damaging earthquakes are known with greatest certainty in these regions. However, other parts of the country are also at risk (although the hazards are more uncertain) and may come more to the forefront with continued research and understanding. These regions include the Atlantic seaboard, which has experienced rare but moderately damaging earthquakes centered near Charleston, South Carolina; Boston, Massachu-

[35] Atkinson, see footnote 31, p. 1; and ibid., p. 8.

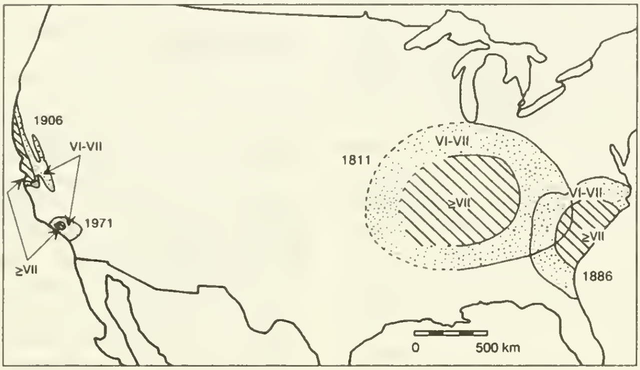
[36] Hamilton and Johnson (eds.), see footnote 34.

[37] Arch C. Johnston and Susan J. Nava, "Seismic Hazard Assessment in the Central United States," *Proceedings of ATC-35 Seminar on New Developments in Earthquake Ground Motion Estimation and Implications for Engineering Design Practice*, ATC-35-1, Applied Technology Council (ed.) (Redwood City, CA: Applied Technology Council, 1994), p. 2-7. An exception is the Meers Fault in Oklahoma, which has geologic expression indicative of previous strong earthquakes but very low modern seismicity.

BOX 2-3: Relative Impact Areas for Eastern and Western Earthquakes

The two halves of the North American continent have very different tectonic histories East of the Rockies, the North American landmass has held together (the abortive Reelfoot Rift notwithstanding) for a good part of the last billion years, and the tectonic plate material is strong In contrast, the continent west of the Rockies has experienced repeated breakup, reassembly, uplift, compression, extension, and shear—heating and weakening it Seismic waves radiating from a western earthquake therefore diminish more rapidly as they pass through fractured and heated rock, so that a major earthquake along the San Andreas can have relatively moderate effects on the distant Los Angeles basin. East of the Rockies, however, seismic waves are far less weakened as they radiate through hard, cold, strong rock, and even a moderate quake has the potential for destruction over a wide geographic range [1]

Relative Impact Areas for Severe Earthquakes in Western and Eastern United States



NOTE Figure shows areas of Modified Mercalli Intensity of VI and VII for two great earthquakes (New Madrid, Missouri, in 1811 and San Francisco, California, in 1906) and two major damaging earthquakes (Charleston, South Carolina, in 1886 and San Fernando, California, in 1971) Potential damage area corresponds to intensity VII and greater, an area of roughly 250,000 square miles for the New Madrid earthquake

SOURCE: Office of Technology Assessment, 1995, based on R Hamilton and A Johnston (eds), *Tecumseh's Prophesy: Preparing for the Next New Madrid Earthquake*, U.S Geological Survey Circular 1066 (Washington, DC U S. Goverment Printing Office, 1990) pp 6, 12, O W Nuttli, "The Mississippi Valley Earthquakes of 1811 and 1812—Intensities, Ground Motion, and Magnitudes," *Bulletin of the Seismological Society of America*, vol 63, 1973, pp 227-248, and D W. Rankin (ed.), "Studies Related to the Charleston, South Carolina, Earthquake of 1886—A Preliminary Report," U.S Geological Survey Professional Paper 1028, 1977

[1] The 1812 New Madrid shock was felt in Boston, Canada, Georgia, and at least as far west as Kansas and Nebraska Moderate ground shaking was felt over an area of nearly 1 million square miles, in contrast to some 60,000 square miles in the 1906 San Francisco quake William Atkinson, *The Next New Madrid Earthquake A Survival Guide for the Midwest* (Carbondale and Edwardsville, IL: Southern Illinois University Press, 1989), p 18

SOURCE: Office of Technology Assessment, 1995 setts; and northward toward the Saint Lawrence Valley.

Puerto Rico and the U.S. Virgin Islands are at risk from earthquakes in the Caribbean's subduction zone. In 1917, Puerto Rico suffered a major earthquake (M7).

Limiting Factors in Assessing Seismic Hazards

Damaging earthquakes have occurred in many parts of the United States, and several metropolitan areas are located in regions of moderate to very high seismic hazards (see table 2-3). Over the last quarter of a century, understanding of these hazards has increased considerably. In the past five years, advanced instrumentation and computer-based analytic tools have revolutionized earth science research and laid the groundwork for new hazard estimation capabilities.

Despite the many achievements to date, uncertainties still plague our ability to characterize seismic hazards. Engineers desire better information on the types of ground shaking expected for a given area so that methods for analyzing and improving a structure's seismic resistance can be enhanced. Likewise, planners and emergency managers would greatly benefit from improved knowledge of which areas in a city are likely to be hardest hit by future earthquakes. Factors that limit our knowledge of faults capable of producing earthquakes, of how often quakes occur on them, and of their likely effects include the following:

- The historical and instrumental records are very short compared with the time scales on which earthquakes are generated, particularly east of the Rockies.
- Most quakes begin rupturing 10 km or more beneath the surface of the earth: although some earthquake phenomena and causative factors are observed directly in surface faulting and geodetic strain, other information must be inferred from seismological and other data.
- Detailed mapping of the structural features that influence earthquake damage has been completed in only a small portion of the United States.
- There are few records of strong ground motions in close proximity to fault ruptures, and data on crustal deformation and stress are likewise sparse.

Such challenges to our understanding of seismic hazards and progress toward the long-term goal of accurately predicting earthquakes will likely be more readily surmounted in the future, given the present confluence of new tools, trained scientists, and expanded databases. These advances stem from work in the earth sciences supported by NEHRP and from other federal, state, local, and international activities.

EARTHQUAKE-RELATED RESEARCH IN EARTH SCIENCE

The preceding sections outlined some of the substantial progress made by the earth science community in achieving a basic understanding of the earthquake problem. This understanding has made it possible for policymakers to identify future trouble spots and to take preventive action. Current knowledge of seismic hazards in different regions, however, has not reached the point where scientists and policymakers are no longer surprised by earthquakes and their effects. Scientific uncertainties for much of the country remain high enough to discourage the implementation of oftentimes costly mitigation measures. Under NEHRP, earth science researchers seek to reduce these uncertainties and to make available much needed information for the implementation of seismic risk reduction policies, practices, and technologies. This section discusses current research efforts that address the primary knowledge gaps.

Objectives

The objectives of current earthquake-related earth science include:

- identifying the regions of potential risk;
- producing or refining estimates of future earthquake location, timing, and severity;
- highlighting special geologic hazards that may accompany future events (e.g., landslides, tsunamis, unusual ground shaking); and

TABLE 2-3: Summary of U.S. Earthquake Hazards

Area	Frequency/probability of return	Comments on tectonic framework
Alaska	Since 1900, one M8 or larger quake every 13 years, one M7+ quake every year, and several moderate to large quakes every year	Subduction zone along Aleutian Islands, Alaskan Peninsula, and southern Alaska. Frequent strong intraplate seismicity. Damaging quakes also possible on strike-slip Queen Charlotte fault in southeast Alaska
Pacific Northwest	90-year return period for a M7 5.	Shallow crustal quakes, massive subduction zone quakes possible offshore, and quakes within subducted plate deep beneath Puget Sound.
Northern California	67 percent chance of a M7 or greater earthquake in the San Francisco Bay area by 2020	Primary faults: strike-slip San Andreas and Hayward/Rogers Creek faults on the east side of the bay; quakes on local blind thrust faults also possible. Northern California coast subject to quakes with several sources: northern segment of the San Andreas, Cascadia subduction zone, and inland crustal quakes
Southern California	80-90 percent probability of a M7 or greater earthquake before 2024 in greater Los Angeles area	Extensive rupture of strike-slip San Andreas possible, and moderate-to-large quakes also likely on secondary fault systems. Extensive buried thrust fault system beneath the Los Angeles basin as a result of compressional terrain. Faults near Los Angeles' and San Diego's port facilities pose a similar threat as the fault that ruptured near Kobe, Japan, in 1995.
Hawaii	Frequent seismicity associated with volcanic activity; last major quake (M7 1) in 1975.	Repeatedly struck by tsunamis; landslide potential high
Intermountain West	30 percent chance of major quake anywhere along Utah's Wasatch fault zone in the next 100 years. Growing population centers elsewhere in Intermountain Seismic Belt also susceptible to damaging earthquakes	Mountain-building region, normal faulting with large vertical offsets possible from Utah northward through Idaho and into Montana.
Central United States	40-63 percent probability of recurrence of M = 6+ quake in New Madrid Seismic Zone before 2005, 86-97 percent probability before 2040, approximately 250-year return period for a M7.6 or greater	Abundant seismicity in New Madrid Seismic Zone, linked to rifted margin; dispersed seismicity elsewhere in the region not linked to specific faults.
Northeast	300-year return period estimated for a M7. Last moderate quakes in New York area in 1944 and 1985	"Stable" plate interior, with zone of relatively high seismicity from Adirondacks up through St. Lawrence Valley; dispersed seismicity elsewhere. Several large earthquakes scattered throughout region since 1600s, primarily in Canadian provinces
Southeast	Charleston, South Carolina, struck by large quake (M6.7) in 1886. High concentration of seismicity in eastern Tennessee.	Tectonic origin for seismicity in eastern United States unclear
Puerto Rico and U S Virgin Islands	Last major quake in 1917, estimated 70-year return period	Subduction zone where the Caribbean Plate meets the North American and South American Plates

SOURCES: Working Group on California Earthquake Probabilities, *Probabilities of Large Earthquakes in the San Francisco Bay Region, California*, U S. Geological Suvey Circular 1053 (Washington, DC. U.S Government Printing Office, 1990), Working Group on California Earthquake Probabilities, "Seismic Hazards in Southern California: Probable Earthquakes, 1994 to 2024," *Bulletin of the Seismological Society of America*, vol 85, No. 2, April 1995, pp. 379-439, R Hamilton and A. Johnston (eds.), *Tecumseh's Prophecy: Preparing for the Next New Madrid Earthquake*, U.S. Geological Survey Circular 1066 (Washington, DC. U S. Government Printing Office, 1990), K. Shedlock and C. Weaver, *Program for Earthquake Hazards Assessment in the Pacific Northwest*, U S Geological Survey Circular 1067 (Washington, DC: U S Government Printing Office, 1991), and Christine A. Powell et al., "A Seismotectonic Model for the 300-Kilometer-Long Eastern Tennessee Seismic Zone," *Science*, vol 264, Apr 29, 1994, pp. 686-688

- supporting scientific and engineering applications of earthquake data and theories.

Meeting these objectives and resolving some of the unknowns laid out in the first half of this chapter requires continued effort in several research disciplines. This work ranges from exploratory research into details of earthquake sources to applying new computational techniques toward predicting ground failure or tsunami development. **Earth science research and data collection efforts have been—and will continue to be—essential to the development and selection of mitigation options appropriate to a particular region's seismic risk.**

For the discussion that follows, earthquake-related research is grouped into two broad areas: 1) basic research into the fundamental processes that govern earthquake timing, location, and severity; and 2) research applied toward predicting the effects of earthquakes, which in turn supports engineering analyses, land-use planning, and emergency response.

Foretelling Earthquake Timing, Location, and Severity

The general theory of plate tectonics, while identifying where earthquakes should occur over the long term, does not itself give clear warning of earthquake likelihood or timing. This stems from the difference between geologic time, which spans thousands or millions of years, and the time scales that are appropriate for public policy. Plate tectonics suggests that if we were to wait several millennia, we would expect earthquakes to occur essentially everywhere along a plate boundary. What it does not tell us is which specific parts of that boundary will become active in the next few years or decades. Moreover, plate tectonics does not easily explain why earthquakes should occur far from plate boundaries (as they do east of the Rockies), and rising evidence suggests that the theory is generally inadequate to describe the large-scale tectonic behavior of continental masses.[38]

To specify which part of a plate boundary is likely to break in the near future, researchers must go beyond the large-scale workings of the basic plate tectonic model and identify how general plate tectonic movements are translated into local earthquakes. This quest entails a host of separate research endeavors, the chief of which are regional tectonic studies, including geodetic studies; fundamental seismological research and monitoring; and paleoseismology. The following sections describe these research areas.

Regional Tectonic Studies

Regional tectonic studies seek to determine how large-scale plate motions produce finer scale patterns of stress and deformation (e.g., uplift and compression of the earth's surface) in potential earthquake zones. If earthquake-causing buildup of tectonic stress can be correlated with the occurrence of tectonic deformation, areas of potential danger can be identified even in the absence of historical seismicity through observing changes in stress. Such an identification would be particularly useful in regions such as the Pacific Northwest where major earthquakes have been historically infrequent.

Tectonic studies also seek to identify hidden structures that are capable of producing earthquakes (e.g., Los Angeles' blind thrust faults) through a combination of remote geophysical techniques and onsite geologic mapping.[39] For example, scientists have studied how the relation-

[38] Current indications are that the thinner oceanic parts of the earth's surface act more plate-like (i.e., they are rigid and strong) but that continents behave in a more complex fashion. For example, the Basin and Range Province of Nevada is stretching in an east-west direction (generating low-level seismicity in the process), while the central and eastern parts of the country seem to consist of strong rigid blocks crisscrossed with weaker scars from ancient tectonic activity.

[39] Methods of imaging subsurface geology and seismogenic structures include analysis of the passage of seismic waves through the earth, and local changes in the earth's magnetic and gravitational fields. When combined, the data reveal variations in material properties or rock types that point to the presence of faults.

BOX 2-4: Geodetic Techniques

Japan initiated the first geodetic monitoring program at the turn of the 20th century, many decades before a similar program was established in the United States.[1] Today, both countries have implemented state-of-the-art observation systems intended to reveal strain and stress accumulation from ongoing tectonic processes. Although geodetic measurements are now made in many areas, in only two areas—the San Andreas strike-slip fault zone and the subduction zone along the southern coast of Japan—are there sufficient data to attempt to reconstruct the entire quake-loading cycle.[2]

Very Long Baseline Interferometry and Global Positioning System

The paucity of data stems in part from the logistics of geodetic measurement techniques, which for years required laborious field surveys. However, the availability of highly accurate clocks and digital telecommunications systems has brought significant advances to the field during the last decade or so. Very Long Baseline Interferometry (VLBI) and, later, Global Positioning System (GPS) satellites have allowed expanded observation of crustal deformation and measurement of slip rates with greater accuracy.[3] GPS-based techniques in particular offer speedier calculations of relative distances and thus deformations. Other technical advantages of GPS systems are: absence of line-of-sight constraints, simultaneous determination of vertical and horizontal position, and a useful interstation range from hundreds of kilometers to less than one kilometer.[4]

Regional networks of continuously recording GPS receivers are operating in Japan and California to monitor strain for earthquake research and forecasting. Deployment of portable stations after an earthquake allows scientists to observe post-seismic deformations, these data complement data from seismographs concerning the depth, orientation, and amount of fault slip.[5]

[1] Christopher H. Scholz, *The Mechanics of Earthquakes and Faulting* (New York, NY Cambridge University Press, 1990), p 223
[2] Ibid., p. 227
[3] VLBI uses radio waves from distant quasars as sources of ranging signals GPS satellites broadcast time-stamped position data at two different frequencies, allowing for correction of signal delays caused by the earth's atmosphere and thus improved resolution
[4] Robert A. Page et al., *Goals, Opportunities, and Priorities for the USGS Earthquake Hazards Reduction Program*, USGS Circular 1079 (Washington, DC: U.S. Government Printing Office, 1992), p 9
[5] University Navstar Consortium, *Geoscientific Research and the Global Positioning System: Recent Developments and Future Prospects* (Boulder, CO: 1994), pp. 3-4 The University Navstar Consortium (UNAVCO) provides information, support, and scientific infrastructure to principal investigators making use of GPS satellites for earth science and related research

ship between primary tectonic features such as the Reelfoot Rift and the continental interior's overall stress regime may serve to localize seismicity in the New Madrid area.[40] Such research may also help to explain the spatial and temporal earthquake clustering that has been observed in the United States and other parts of the world.

Geodetic Studies

A number of technologies (see box 2-4) are used to observe and measure tectonic deformation. These geodetic studies provide part of the raw material for tectonic studies and serve as intermediate checkpoints for earthquake forecasts based on

[40] A current hypothesis is that most stable continental quakes occur through the reactivation of relatively young rift faults that break the integrity of the continental crust. John Adams and Peter W. Basham, "New Knowledge of Northeastern North American Earthquake Potential," ATC-35-1, p. 3-7, citing Coppersmith et al., *Methods for Assessing Maximum Earthquakes in the Central and Eastern United States: EPRI Project 2556-12*, Working Report (Palo Alto, CA: Electric Power Research Institute), 1987; and A.C. Johnston, "The Seismicity of 'Stable Continental Interiors'" *Earthquakes at North Atlantic Margins: Neotectonics and Postglacial Rebound*, S. Gregerson and P.W. Basham (eds.) (Dordecht, Netherlands: Kluwer Academic Publishers, 1989), pp. 299-327.

BOX 2-4 (cont'd.): Geodetic Techniques

Synthetic Aperture Radar Imagery

An even more recent departure from established ground-based geodetic measurement techniques is the use of remote sensing to produce detailed images of deformation fields Microwave signals generated by synthetic aperture radar (mounted on aircraft or satellites) and reflected off the ground are processed to estimate displacement.[6] Unlike most geodetic techniques, a surveyed network need not be in place prior to an earthquake—satellite images collected at regular intervals can capture co-seismic displacements without advance knowledge of an earthquake's location.[7] Other advantages of Synthetic Aperture Radar imagery include more dense spatial sampling and better precision than previous space imaging techniques.

Laser Interferometry

Near Parkfield, California, the U.S. Geological Survey has been using a two-color laser distance measuring instrument (geodimeter) to observe relative movement in the vicinity of the San Andreas fault. The two-color geodimeter measures distances to a precision of 0.3 to 1.0 mm for ranges between 1 and 9 km.

In-fault Measurements

A number of instruments placed at various depths in an active fault zone also help to reveal ongoing deformation either directly (e.g., through creepmeters and strainmeters) or indirectly (e.g., through changes in water level or pore pressure). Creepmeters continuously monitor fault movement within a few meters of fault zones to characterize the rate and nature of fault slip. They can detect changes of about 0.1 mm. Borehole volumetric strainmeters can detect changes of 10 parts per billion (1 inch in 1,600 miles) for signals with periods of several weeks and, for higher frequency signals, can detect even smaller changes.

[6] William Prescott, "Seeing Earthquakes from Afar," *Nature*, vol. 364, July 8, 1993, pp. 100-101

[7] Didier Massonnet et al., "The Displacement Field of the Landers Earthquake Mapped by Radar Interferometry," *Nature*, vol 364, July 8, 1993, p 138

SOURCES: Office of Technology Assessment and U.S Geological Survey, 1995

models of regional tectonics. For example, geodetic data are used to infer rates of regional plate motion that, along with seismologic or geologic evidence of fault locations, can provide estimates of the hazard from these faults.[41] Important data are also obtained from strain measurements at depth (e.g., through borehole monitoring of porosity).

The advent of space-based geodetic techniques, such as Very Long Baseline Interferometry, Satellite Laser Ranging, and most recently, surveys using the Global Positioning System (GPS), has revolutionized this field of study.[42] With these newer techniques, it is possible to directly observe crustal deformation, which may ac-

[41] USGS and SCEC Scientists, see footnote 25, p. 395.

[42] The first two technologies were developed under the aegis of the National Aeronautics and Space Administration's (NASA) Crustal Dynamics Project, a program aimed at directly measuring the relative velocities of tectonic plates on a global scale; the original geoscientific applications of GPS stemmed from this work. University Navstar Consortium, *Geoscientific Research and the Global Positioning System: Recent Developments and Future Prospects* (Boulder, CO: 1994), p. 1. Today, under NASA's Mission to Planet Earth Program, space-based geodetic technology development and research continues.

celerate the development of reliable earthquake forecasting.

Fundamental Seismological Research

To better understand how stresses in the earth eventually lead to the rupturing of a fault and the production of an earthquake, scientists monitor earthquakes via global and regional seismic networks (coordinated systems of sophisticated seismic listening and measuring devices, known as *seismometers*; see box 2-5) and compare the seismology data collected with results from theoretical and laboratory models of earthquake generation.

Questions central to seismological research include the following:

- How does an earthquake initiate?
- What determines whether a growing earthquake becomes large, moderate, or small?
- Can a prenascent earthquake telegraph its future birth and characteristics to attentive observers?
- How does an earthquake affect tectonic stress in a region (e.g., does it simply alleviate stress and thus reduce the likelihood of an imminent recurrence, or can an earthquake create distortions in the regional stress field that set off nearby followers)?

The advent of faster, more powerful computers has aided in understanding the processes by which crustal stresses lead to earthquakes at any given location. Using seismological data, researchers now model how fractures initiate and propagate as a result of mechanical properties (e.g., frictional strength) and stress changes at each point on the fault. In addition, three-dimensional models of ruptures along segmented faults are being developed to study what stops earthquakes and thereby to estimate their magnitudes.[43]

Another effort to understand what controls earthquake faulting involves laboratory studies of the physical properties of earth materials and physical conditions at the earthquake source, the interactions between rock and fluid in the fault, and nucleation and instability mechanisms.[44] The objective is to improve tools for interpreting observations of seismic and geodetic data in terms of earthquake processes and conditions at the source.

Paleoseismology

On most faults, the time between similar large earthquakes is much longer than the period over which modern instruments have observed earthquakes and geodetic changes. Even in regions where recorded history spans thousands of years, such as the eastern Mediterranean or north-central China, contemporary observers often could not correlate earthquakes with specific faults.[45] Thus our knowledge of how often faults can produce damaging earthquakes is very limited.

To learn whether or not earthquakes consistently rupture the same segment of a fault in the same way (i.e., act as a characteristic earthquake) or follow a regular time pattern, it is necessary to extend the modern record back long enough to encompass several similar earthquakes on the same fault. This need led to the development of paleoseismology, a relatively new field of earth science. Researchers seek and examine evidence of sudden coastal subsidence or uplift; fault displacement revealed by shallow excavations; and deposits related to liquefaction, tsunamis, or other seismically induced processes. In many cases, paleoseismic events can be dated by radiocarbon and other techniques, although typically not with as much precision as historical events.[46]

With funding from NEHRP, this type of data collection has accelerated in the past 15 years. Paleoseismology has been particularly useful in as-

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[43] Ruth Harris, U.S. Geological Survey, Menlo Park, personal communication, Nov. 4, 1994.

[44] James Dieterich, U.S. Geological Survey, Menlo Park, personal communication, Nov. 4, 1994.

[45] This section is drawn from Robert Yeats, Department of Geosciences, Oregon State University, personal communication, May 7, 1995.

[46] Kenneth A. Geottel, Goettel & Horner, Inc., personal communication, May 7, 1995.

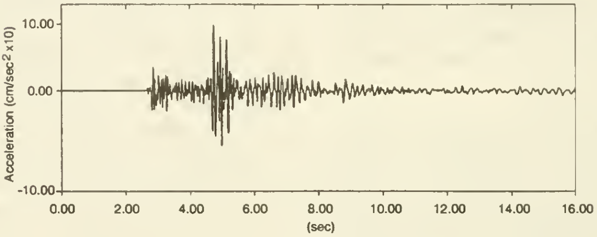
BOX 2-5: Seismic Monitoring

Seismic monitoring serves several purposes: it allows determination of the location of significant earthquakes in support of emergency response and public information; it enables nuclear test ban verification; and it supports research directed at improving basic understanding of tectonics and earthquake phenomena.

In the 19th century, knowledge of major seismicity was for the most part limited to earthquakes felt on the continents.[1] The installation and operation of seismometers in many countries, along with extensive cooperation in exchanging data, have since permitted knowledge and illustration of global patterns of seismicity. The 1960s witnessed the establishment of a global network of seismic stations (largely with nuclear monitoring in mind), at the same time, several regional seismic networks were established in the United States. As of 1994, there were more than 1,400 permanent seismographic stations maintained by regional networks.[2]

Two primary classes of seismometers exist today: 1) 1960s-generation equipment that provides data in limited frequency and amplitude ranges, largely because of analog transmission constraints, and 2) new generation broadband, high-dynamic range instruments available since 1985. The advanced instruments and digital telemetry now enable improved representation of the phase and energy spectra of seismic waves, essential to ground motion and earthquake processes research. With constrained resources, however, there are tradeoffs between increasing the quality or the quantity of instruments. Likewise, there is tension between providing funding for the operation and maintenance of stations and performing research with the available data.

Seismogram of Northridge Aftershock



NOTE: Vertical component of acceleration recorded in the San Fernando Valley from a magnitude 4.5 aftershock of the 1994 Northridge earthquake.

SOURCE: U.S. Geological Survey, 1995.

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[1] Bruce A. Bolt, *Inside the Earth: Evidence from Earthquakes* (San Francisco, CA: W.H. Freeman and Co., 1982), p. 54.

[2] Council of National Seismic System, "CNSS Seismic Natworks and Data Centers" internet address http://www.geophys.washington.edu/CNSS/cnss.sta.html, May 11, 1995. CNSS was begun at a meeting in Denver in February 1993 by representatives from most of the U.S. regional seismic networks and the National Seismic Network to help coordinate efforts to record and analyze seismic data in the United States. As of spring 1995, 27 institutions had formally joined the council.

(continued)

BOX 2-5 (cont'd.): Seismic Monitoring

National Seismic Network

In the late 1980s, the Nuclear Regulatory Commission decided to withdraw support for its networks, located primarily in eastern states The U.S. Geological Survey proposed to establish the National Seismograph Network (NSN), a 150-station network of modern digital stations distributed throughout the country, to enable uniform monitoring of significant quakes and provide data for research into a variety of earthquake problems. To date, 23 NSN broadband seismic stations have been installed in the eastern United States, with nine more stations planned. In the western United States, 16 NSN broadband stations are operating, and seven more are planned. Installation of an additional 10 to 15 cooperative NSN stations is possible over the next few years for the continental United States.[3]

NSN is not intended to perform the monitoring and research functions of the existing regional networks Rather, it leverages their capabilities with technology for recording broadband, high-dynamic range, three-component seismic data in real time and with low telemetry costs. In addition, NSN provides standardized data manipulation procedures and a communications network that interconnects regional networks.[4]

[3] Harley Benz, U.S Geological Survey, personal communication, May 11, 1995.

[4] Thomas H. Heaton et al., "National Seismic System Science Plan," U S Geological Survey Circular 1031 (Washington, DC U S Government Printing Office, 1989), pp 21-22.

SOURCE Office of Technology Assessment, 1995.

sessing earthquake potential in regions that have not been struck by a major earthquake during recorded history, such as the Salt Lake City metropolitan corridor, the San Andreas fault in southeastern California, and the Cascadia subduction zone in the Pacific Northwest. It has also helped to reduce uncertainty about the frequency of major quakes in the central United States, and to enhance knowledge of historic earthquakes in the San Francisco Bay area.[47]

Earthquake Forecasting and Prediction

A longstanding objective of efforts to understand basic geological and seismological processes is a reliable means of predicting earthquakes.[48] The simplest model of the earthquake cycle is that strain accumulates, is released in an earthquake, and accumulates again—initiating another cycle. The average length of the cycle for a certain type of quake at a given location is called the recurrence interval, which is used to roughly estimate the time of the next earthquake. To determine this interval, scientists rely on seismic monitoring and paleoseismology to obtain relationships for magnitude and recurrence.

Historical seismicity and paleoseismology show, however, that there is great variability in the timing, location, and magnitude of earthquakes. The variations in earthquake characteristics on a single fault segment or the clustering of several

[47] In spite of the fact that *paleo* means ancient, paleoseismologists study both prehistoric and historical earthquakes—in areas having short historic records, there may be only one example of an earthquake on a given fault. Carol Prentice and Andrew Michael, U.S. Geological Survey, Menlo Park, personal communications, June 5, 1995.

[48] This report distinguishes between forecasting and prediction as follows: the former refers to estimates of earthquake potential or timing over a period of many decades; the latter encompasses estimates of earthquake occurrence on shorter time scales (e.g., imminent—a few seconds or minutes; short-term—several minutes to days or weeks; and intermediate-term—up to several years).

TABLE 2-4: Comparable Seismic Zones

U.S. region	International counterpart
New Madrid Seismic Zone and eastern United States	Australia, peninsular India
California	New Zealand, northeastern Iran, Mongolia, Turkey, Venezuela
Intermountain West	North-central China, Aegean region of Greece and western Turkey
Pacific Northwest	Southwest Japan, southern Chile

SOURCE Robert Yeats, Department of Geosciences, Oregon State University, personal communication, May 7, 1995

earthquakes in time indicate that the simple model is not sufficient for many applications. Some areas exhibit greater variability than others; typically, these are regions of more complex geology and plate interaction. Several U.S. metropolitan centers are located in such regions (e.g., Los Angeles, San Francisco, and cities in the Pacific Northwest).

To improve on the simple earthquake model requires a better understanding of the processes through which tectonic stress leads to individual earthquakes. This entails developing models of earthquake generation and relating these models to things we can observe in the earth (some of which may turn out to be earthquake precursors). Therefore, current efforts at earthquake prediction combine historical seismological and paleoseismological data with models of earthquake generation, and correlate the results with measurements of geophysical phenomena.

Forecasts

In a few regions of the country, scientists have gathered enough data to permit long-term earthquake forecasts; these are often expressed as the probability that a certain size earthquake will occur within the next few decades, either for a single fault (e.g., the southern San Andreas or Wasatch) or for a region with several hazardous faults (e.g., the San Francisco Bay area).[49] Such probabilistic assessments have been important in analyzing a region's seismic hazard, and directly support land-use planning and building code development.[50]

Because individual earthquakes repeat so infrequently and because there is variability between events, these forecasts are subject to considerable uncertainty. We can develop and test improved models more rapidly if we also look outside the United States for data, especially to other parts of the world that have similar geologic settings and have had large historical earthquakes. Table 2-4 lists these areas and their international counterparts.

Prediction

In theory, prediction could stem from improvements to the probabilistic forecasting method—that is, through reducing uncertainties in the assessment of earthquake characteristics and timing to permit more precise estimates. But variability in earthquake events is not the only source of uncertainty; the probabilistic method is also hampered in areas where quakes are very infrequent or have poor surface expression, and where geophysical and geodetic data are sparse. Intraplate quakes, in particular, tend to have very long recur-

[49] A probabilistic forecasting model, for example, incorporates the regional stress field, rate of crustal deformation in the vicinity of the fault, and strain accumulation with seismologic and geologic data.

[50] Estimates of earthquake potential are also used in *deterministic* assessments of seismic hazards (i.e., the calculation of strong ground motions for a specific earthquake scenario and site); these are frequently used in building design and the construction of seismically resistant structures.

rence times (e.g., thousands of years), and few have surface expression.

Thus earthquake prediction may hinge on interpreting certain warning signs rather than enhancing current models of the seismic cycle. As a first step, it is essential to verify whether or not such signs exist. Box 2-6 discusses research questions related to earthquake prediction.

Foretelling Earthquake Effects

In addition to determining earthquake potential, an equally important task for the earth science community is to give planners and engineers precise information on what earthquakes will actually do to the earth's surface that threatens the built environment. Earth science R&D with more immediate application to mitigation has historically been overshadowed by the basic research disciplines, but is now receiving increased emphasis (a breakdown of funding levels is given in appendix B). This applied research is of great importance for two reasons.

First, because earthquake effects on the earth's surface are complex, improving the seismic resistance of lifelines, buildings, and their contents requires detailed knowledge of the physical forces they will encounter. Second, the initial expenses of some mitigation measures are such that at-risk communities may have difficulty implementing them. The use of broad-brush, regionwide mitigation measures is often constrained by political and economic concerns (see chapter 4). Research that can identify locations of extreme danger and areas of relative safety can thus allow communities to target limited resources to where they will do most good.

This work includes the fields of strong-motion studies and seismic zonation (and its subset, microzonation).[51] Its objective is to examine—and quantify where possible—how seismic waves interact with particular aspects of local geology and geography to produce potentially damaging effects, including ground shaking, soil amplification, liquefaction, and tsunamis. The following discussion explains related studies and their applications in more detail.

General Ground Shaking

To design buildings and other structures that resist seismic damage, the engineering community requires quantitative estimates of the accelerations, velocities, and displacements that will occur in future earthquakes. Producing such estimates requires knowledge of:

- future earthquake magnitude;
- the location, orientation, and size of the likely earthquake fault;
- the attenuation characteristics of geologic material lying between the earthquake location and the area of concern (to determine how rapidly seismic waves decay with distance from the epicenter); and
- the general soil characteristics of the region.

This work is partly theoretical and partly empirical; it typically involves the correlation of laboratory predictions with data recovered from strong-motion seismometers in real-world earthquakes[52] (see box 2-7). Useful data can also be obtained by temporary regional-scale seismic networks deployed in an earthquake's aftermath to record the effects of aftershocks.

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[51] *Strong-motion studies* focus on the shaking effects that seismic waves impose on the earth's surface, while *zonation* is a broader field that incorporates such indirect earthquake hazards as landslides and tsunamis, as well. *Microzonation* is hazard assessment on the scale of a town or city block.

[52] Strong-motion devices differ from traditional seismometers in that they can record the strong, violent ground motions from a nearby earthquake without failing or going off-scale (traditional observatory-grade seismometers are sensitive instruments designed to detect the faint tremors from distant seismic events and cannot handle strong shocks). Gathering strong-motion data has thus historically meant the deployment of specialized instruments for the task. However, recent technical developments have allowed some modern seismometers to function both as strong-motion instruments and as observatory devices, and they are increasingly used in many of the newest seismic networks.

BOX 2-6: Earthquake Prediction

To date, programs directed at predicting earthquakes have had mixed success The central questions include 1) are there specific physical conditions that indicate the location, timing, and size of future earthquakes, 2) are current research programs adequately designed to capture and permit assessment of potential precursors?

- **Is there a recognizable pattern to earthquakes?**

Through statistical analysis of worldwide earthquake occurrences, one can estimate the frequency of different magnitude quakes across the globe The monitoring of global seismicity also makes it clear that certain areas are much more prone to quakes than others—90 percent of the world's earthquakes occur on the boundaries of large tectonic plates

Along a single plate boundary, however, there can be considerable variability in the size and frequency of significant earthquakes For example, parts of the San Andreas fault accommodate the relative motion of the North American and Pacific Plates without earthquakes (i e., through aseismic slip); other sections of the fault have experienced several large or major quakes during recorded history In general, intraplate earthquake sources and processes are even less well known Thus, a better understanding of the relationships among plate tectonics, regional stresses, and earthquake sources is needed

- **Is an earthquake's size "known" at the time of its initiation?**

Scientists are making progress in understanding earthquake genesis and growth, although there is not yet consensus on whether the eventual magnitude of the quake is random or somehow programmed into the surrounding rock. Recent observations of earthquake sources using advanced seismographic instruments, however, show that earthquakes initiate with a distinctive seismic nucleation phase and that the size and duration of the nucleation phase appear to scale with the eventual size of the earthquake.[1] These new and somewhat controversial results suggest that conditions favoring the growth of large, potentially destructive earthquakes are fundamentally different from those that lead to more common, smaller events If so, careful geologic and geophysical monitoring might someday detect the conditions that signal the imminent risk of a large earthquake

Local geology (and topography) may also have a role in whether larger, less frequent quakes (or smaller, more frequent ones) are to be expected on a fault.[2] Advanced models of rupture propagation, additional geophysical data, and additional seismological data from newer broadband, high-dynamic range instruments will likely aid in understanding how surficial and subsurface fault characteristics affect rupture and maximum magnitude

- **Does the state of stress that causes an earthquake to initiate and a fault to rupture betray itself through characteristic signals?**

The standard approach to developing a prediction capability hinges on the earth's providing recognizable signals of impending quakes. Ideally, much as we have come to associate certain symptoms with the onset of a cold, scientists could detect reliable indicators of an earthquake's occurrence in advance of the event itself

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[1] W L. Ellsworth and G C. Beroza, "Seismic Evidence for an Earthquake Nucleation Phase," *Science*, vol 268, 1995, p 851.

[2] Scientists look for the presence of rough patches in the fault (asperities) through analysis of seismograms, physical separation (e g , step-overs) between fault segments, or other geologic barriers to the spread of the rupture zone

(continued)

BOX 2-6 (cont'd.): Earthquake Prediction

Theoretical and laboratory studies indicate there should be a preliminary phase prior to rupture Potential earthquake precursors include foreshocks (as material starts to fail under the extreme stress or strain), changes in the groundwater table (these occur when water-bearing pores in the rock start to deform under the stress) and other hydrologic or hydrothermal phenomena, deformation of the earth's surface, changes in the rock's electrical conductivity or magnetic properties, and changes in seismic wave properties through the area in question In the past, such phenomena have been observed in the field, but not consistently.[3]

Broad efforts to identify potential precursors are being pursued in China, Japan, and the former Soviet Union through extensive monitoring of seismicity, crustal deformation, and a variety of other phenomena Chinese scientists were able to predict the 1975 M7 4 quake in Haicheng and the August 1976 M7.2 Songpan earthquake.[4] However, they were unable to predict the July 1976 Tangshan earthquake (M7.8), which killed hundreds of thousands In Japan, public warning was achieved for the 1978 Izu-Oshima earthquake (M7).[5] Japan's monitoring and prediction program focuses primarily on the region surrounding Tokyo, which has the highest seismic risk. The Kobe locale, assigned a very low hazard, received little prediction attention.

It is important to note that Japan's monitoring program is directed at subduction zone earthquakes and may not be applicable to the strike-slip boundary on the U S West Coast [6]

Earthquake Prediction in the United States

The first U.S effort directed at earthquake prediction was located near the central California town of Parkfield, adjacent to the San Andreas fault. The Parkfield prediction experiment was begun in 1985 after analysis of previous earthquake occurrences on a particular fault section indicated that a repeat event would occur near the end of the decade [7] The expected "characteristic earthquake" did not happen within the prediction window

Further analysis showed that, while the successive repeat of similar (but not identical) quakes might be expected on individual fault sections, the amount of time between them may be highly variable Confidence in predictions based on estimations of recurrence intervals has decreased; scientists are more sanguine about the possibility of identifying one or more of the "red flags" described above [8]

Today, the Parkfield experiment operates 21 instrument networks to record pre-earthquake phenomena (e.g , strain transients, electromagnetic signals); five of these networks are monitored in real time Ten additional networks are in place to record strong ground motion, co-seismic slip, and liquefaction.[9]

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[3] Paul Silver, Department of Terrestrial Magnetism, Carnegie Institution, personal communication, Apr 5, 1994

[4] Cinna Lomnitz, *Fundamentals of Earthquake Prediction* (New York, NY John Wiley & Sons, Inc., 1994), pp 22, 29-30 Some argue that the Haicheng quake was easy to predict because there were many foreshocks the day before the main shock

[5] Evelyn Roeloffs and John Langbein, "The Earthquake Prediction Experiment at Parkfield, California," AGU *Reviews of Geophysics*, vol. 32, No 3, August 1994, p 315

[6] The Japanese program has also been the subject of much criticism for its expense, lack of openness, and lack of results See, e.g , Robert J Geller, "Shake-up for Earthquake Prediction," *Nature*, vol 352, No 6333, July 25, 1991, pp 275-276

[7] Parkfield has experienced moderate quakes six times since 1857 In 1985, on the basis of this sequence, the recurrence interval for M6 quakes near Parkfield was estimated to be about 22 years, and it was estimated with 95 percent confidence that another similar event would occur before 1993 Roeloffs and Langbein, see footnote 5, p 315, citing W H Bakun and A G Lindh, "The Parkfield, California, Earthquake Prediction Experiment," *Science*, vol 229, 1985, pp 619-624

[8] Silver, see footnote 3

[9] Roeloffs and Langbein, see footnote 5

BOX 2-6 (cont'd.): Earthquake Prediction

Assessing Prediction Feasibility

For prediction to be feasible, however, scientists must be able not only to recognize the red flags, but also to determine the relationship between these precursors and succeeding earthquakes. In addition, the red flags must have some predictive power; that is, there must be a sound correlation between their occurrence and the subsequent occurrence of significant earthquakes [10]

According to some scientists, while the current monitoring program at Parkfield may yield useful data for that specific spot, it is not comprehensive enough to verify whether or not prediction is feasible. Instead, they advocate a more extensive program to monitor multiple types of potential precursors throughout the San Andreas fault zone. New observation techniques (e.g., space-based geodetic surveys and imagery of crustal deformation) could provide the necessary broad coverage and complement in situ monitoring and fault studies.

Given the complexity of such an undertaking, as well as the relative infrequency of damaging U.S earthquakes, results from this effort might not be expected for another few decades.

[10] Silver, see footnote 3

SOURCE. Office of Technology Assessment, 1995

Early Warning

Advances in seismometers and telecommunications, along with automated analysis of earthquake events, may soon permit early warning of seismic waves capable of producing strong ground motion. Because electronically transmitted information travels at a much faster rate than seismic waves travel through the earth, real-time warning of severe shaking approaching a populated area or lifelines will be possible given monitoring systems that can automatically determine a quake's location and magnitude and estimate the strong-motion characterictics within a few seconds.[53] Early warning systems hold the potential for automated response during an earthquake and more rapid, effective response after the shaking stops.

Amplification Effects

Engineers and planners within specific communities also must be aware of the possibility of localized, unusually high amounts of ground shaking. These "hot spots" can result from simple soil amplification, in which the presence of soft soils and sediments at the earth's surface significantly increases the amplitude of passing seismic waves (see figure 2-8).

The collection of ground motion records from recent large California quakes and their aftershocks, as well as from recent events in Mexico and Japan, has aided in understanding site effects in these areas.[54] However, records for other areas of the United States are very limited. In addition, significant geotechnical modeling is still needed

[53] Post-earthquake notification systems have been operating in southern California since 1991 and in northern California since 1993. System operators expect to achieve early warning capabilities within a few years.

[54] Stephen Hartzell, U.S. Geological Survey, Earthquake and Landslide Hazards Branch, personal communication, Oct. 20, 1994.

BOX 2-7: Strong Motion Recording

Beside the seismometer, another essential tool for defining the impact of a quake is the strong-motion accelerograph, typically housed in or near buildings, dams, and other critical engineered structures. *Strong motion* is used to mean ground motions that are sufficiently large to cause damage to structures; a strong-motion accelerograph is intended to record these large motions without signal saturation. The data generally are used for engineering purposes and, until recently, the instruments were usually triggered only by events of a minimum magnitude (e.g., M4.5 for local events or higher for distant quakes).

The development of regional seismographic networks began in the 1960s in response to the need to learn more about the distribution of seismicity with areas of recognized earthquake hazards Because the primary objective of their implementation was the construction of a catalog of earthquake activity with high spatial resolution, the seismometers were adjusted to record smaller, more numerous earthquakes. This, combined with the use of analog data telemetry to meet high sample rate requirements and an emphasis on high-frequency ground motions, limited the effective dynamic range of the monitoring networks. As a result, the recording of strong ground motions was largely sacrificed

Now, digital strong-motion instruments are being integrated into seismic observatories that record both weak and strong ground motions.

The majority of strong-motion networks are located in the western states, with these instruments, scientists and earthquake engineers have obtained a fairly extensive strong-motion data set for the southwestern United States. Few records exist for other parts of the country and, more importantly, there are no near-field records from damaging quakes in U.S. urban centers. This means that scientists and engineers still lack empirical knowledge of the effects of earthquakes that occur directly beneath densely populated areas.[1]

[1] The 1994 Northridge quake occurred in a largely suburban area, and its largest motions were focused toward less populated areas. The ground motions in downtown Los Angeles produced by a quake on the buried Elysian Park thrust fault, for example, would likely be much larger than those experienced above the source of the Northridge quake Likewise, the 1989 Loma Prieta quake occurred several miles from heavily populated centers in the San Francisco Bay area.

SOURCE: Office of Technology Assessment, 1995, based on Thomas H. Heaton et al., "National Seismic System Science Plan," U.S. Geological Survey Circular 1031 (Washington, DC U.S. Government Printing Office, 1989).

to address several facets of site response, including soil properties, stratigraphy, and ground motions that occur in the immediate vicinity of a fault.[55]

Other factors in unusual ground shaking are: 1) basin effects, in which sedimentary basins (large, bowl-shaped deposits of river or lake-borne sands, soils, and clays, on which most of the country's urban centers are built) trap, accumulate, and amplify passing seismic waves (see box 2-8); and 2) ridge effects, in which topographic features such as hills and valleys can focus seismic waves together in the manner of a lens.[56]

[55] Examples are: nonlinear response of soft, weak soils; deep basin response; deep cohesive sites and shallow, stiff soils; two- and three-dimensional topographic and stratigraphic effects; and near-field motions and spatial incoherence. Ray Seed, Earthquake Engineering Research Center, University of California, Berkeley, personal communication, Nov. 3, 1994.

[56] Amplification and basin effects were largely responsible for the unusual amount of devastation wrought in the Mexico City earthquake of 1985, as well as for damage to the Marina District of San Francisco in the 1989 Loma Prieta quake. Ridge effects in the Loma Prieta event are thought to have been responsible for vertical accelerations in excess of 1 g in certain severely damaged neighborhoods.

Predicting amplification effects is in theory straightforward, since the scientific principles involved are well understood. However, accurate estimates require detailed knowledge of local geology (which typically demands a special effort), as well as specific predictions of the future earthquake's source characteristics (i.e., fault rupture characteristics and the consequent nature of the initial seismic waves).

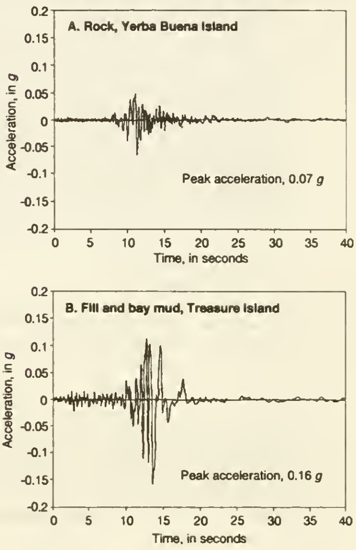
Ground Failure

Combining knowledge of the potential for strong shaking and of local geology and soil conditions yields an improved capability to identify the potential for liquefaction, landslides, and other forms of ground failure. When water-saturated soils and sediments turn into a quicksand-like slurry during extended shaking, they lose the ability to bear loads, thus causing even seismically resistant buildings and structures to fail at the foundation. Lateral spreading or permanent ground displacement also can cause great damage to buried utilities or port facilities. These phenomena are of particular concern to planners and local policymakers, because sites prone to such failure may require extraordinary preventive measures or relegation to less vulnerable forms of land use.

Geographical Information System (GIS) tools have been increasingly utilized in assessing these hazards and in analyzing related risks to special facilities or structures. Primarily a research tool today with respect to earthquake hazards, GIS-based maps can be readily converted to a larger educational—or policy—tool as well.[57]

In addition, systems have been proposed for both northern and southern California that will incorporate knowledge of a quake's location, size, and faulting mechanism into preexisting databases on shallow soil structure and the built environment.[58] Their objective is to quickly map the zones with most severe ground motion, which will indicate where emergency managers should look

FIGURE 2-8: Effects of Local Geological Conditions on Ground Motion



NOTE: Recorded horizontal ground motion (east-west direction) from the 1989 M7.1 Loma Prieta earthquake.

SOURCE: U.S. Geological Survey, 1995

for the most damage and should direct response teams.

Tsunamis and Seiches

In addition to knowledge of the hazardous effects described above, coastal communities also require warnings of the possibility of tsunamis and

[57] Arthur C. Tarr, U.S. Geological Survey, Earthquake and Landslide Hazards Branch, personal communication, Oct. 21, 1994.

[58] Barbara Romanowicz, Seismic Research Center, University of California, Berkeley, personal communication, Nov. 3, 1994.

BOX 2-8: Basin Effects

Most of the large urban areas in the United States have developed on sediment-filled basins, which can strongly modify the ground motion from an earthquake.[1] It is believed that the shape and material properties of a sedimentary basin allow it to focus and collect seismic waves.[2] The result is large-amplitude surface waves that reverberate long after the rupture itself has ceased. Until recently, however, models of the earth's structure and wave propagation could not represent these conditions.

Under NEHRP, the U.S. Geological Survey is applying new three-dimensional modeling techniques to the case of complex propagation effects for the San Bernardino Valley east of Los Angeles, through which the San Andreas fault passes. The simulated effects include high ground velocities in localized portions of the basin, which could pose significant risk to structures with natural periods of one second or longer (e.g., buildings of 10 or more stories, some highway overpasses, and elevated pipelines).[3] Similar studies are under way for the San Francisco Bay area and Washington State's Puget Sound region.

[1] Stephen Hartzell, U.S. Geological Survey, Earthquake and Landslide Hazards branch, personal communication, Oct. 20, 1994.

[2] Thomas H. Heeton and Stephen H. Hartzell, "Earthquake Ground Motions," *Annual Review of Earth Plantary Science*, vol. 16, 1988, p. 127, citing J. A. Riel, "Caustics and Focusing Produced by Sedimentary Basins, Applications of Catastrophe Theory to Earthquake Seismology," *Geophysical Journal of the Royal Astronomical Society*, vol. 79, 1984, pp. 923-38.

[3] Arthur Frankel, "Three-Dimensional Simulations of Ground Motions in the San Bernardino Velley, California, for Hypothetical Earthquakes on the San Andreas Feult," *Bulletin of the Seismological Society of America*, vol. 83, No. 4, August 1993, p. 1021.

SOURCE: Office of Technology Assessment, 1995.

seiches. Research into these hazards—which seeks to understand why they are generated by some earthquakes and not others—blends the scientific fields of seismology and oceanography. Such research has a considerable international component (although tsunamis and seiches do take place in the United States, considerably more experience has been gained by Japan and other countries of the far Pacific Rim) and is frustrated by the unusual physical characteristics of the phenomena. Tsunamis, for example, exist in the open ocean as extremely fast, extremely broad, but extremely low waves that can pass beneath ships completely undetected.[59] Given these characteristics, specialized tsunami detection equipment is necessary both for research and for establishing early warning systems for coastal communities.[60] The National Oceanic and Atmospheric Administration operates the U.S. tsunami warning system.

A common thread in all these applied research efforts is that they require collaboration between specialists in the traditional seismic research community and practitioners in other earth science and engineering disciplines. Moreover, the work cannot be accomplished purely through theory or lab-

[59] The danger of tsunamis is that, although extremely low in the open ocean (only inches high), they are long enough to contain a considerable amount of water (tsunami waves can stretch a hundred miles crest to crest), and fast enough to propel that water far inland. Speeds of hundreds of miles per hour are common. In a damaging tsunami strike, the incoming wave slows down as it approaches land. As it slows, the back of the wave catches up with the front, the wave height builds to many tens of feet, and the wave ultimately washes ashore as a huge surge of water.

[60] Because tsunami waves are so broad and low, their detection in the open ocean requires devices akin to tide gauges (i.e., instruments that can detect the passage of an open-ocean tsunami amid normal wind-driven waves).

oratory experiments; gathering detailed geologic information on each region or locality of interest requires a concerted effort.[61]

For example, the U.S. Geological Survey prepares maps of seismic hazards on national and regional scales, using a variety of data sources and modeling techniques (see figure 2-9). Maps of expected ground shaking are converted by the engineering community into design maps that reflect current engineering analyses; they form the foundation for model seismic codes. In addition, regional hazard maps support state and local land-use planning efforts, and can pinpoint areas where further study is warranted.


STEINBRUGGE COLLECTION, EARTHQUAKE ENGINEERING RESEARCH CENTER

Valdez, Alaska, waterfront after tsunami caused by 1964 Good Friday earthquake.

SUMMARY AND KEY FINDINGS

Earthquake hazards vary widely across the United States. The most active seismic regions in the United States are Alaska and California; their high seismicity stems from proximity to the boundaries between shifting segments of the earth's crust. However, few parts of the United States are immune to quake hazards. Significant earthquakes have occurred in the Pacific Northwest, in the central United States, and along the east coast.

Earth science research, in which NEHRP has played a key role, has advanced significantly our understanding of U.S. seismic hazards. It is now possible to estimate the likelihood of future earthquakes for a few areas (the San Francisco Bay and greater Los Angeles areas, where many years of study have helped to reduce uncertainties; Utah's Wasatch fault zone; and the New Madrid Seismic Zone). In the near future, scientists may be able to do the same for other regions of the United States.

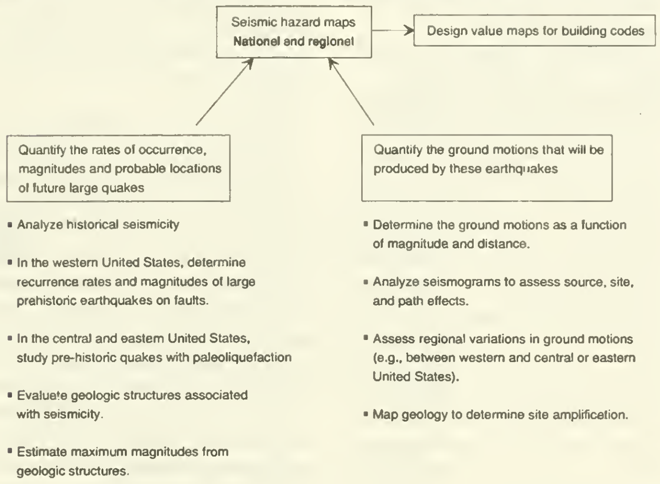
The importance of local soil conditions and other factors that influence the type and degree of damage an earthquake can cause (e.g., soil amplification and landslides) are now recognized and better understood. It is now possible to produce detailed maps showing specific hazards resulting from local soils, and provide more detailed and accurate expected ground motion information for use in building design and model code development. Within a few years, researchers expect to be able to provide real-time warnings of approaching strong shaking.

Despite the numerous advances, however, significant uncertainties and knowledge gaps remain. Scientists are far from able to determine the specific time, location, and magnitude of future earthquakes. Among the key unknowns are questions about the constitutive properties of faults, the interactions of different fault systems, and the mechanisms of rupture. Additionally, in many areas of the country, the location of faults capable of producing damaging earthquakes is still not known, nor is the likelihood of these earthquakes or the extent of their hazardous effects.

There are many societally useful directions for future earthquake-related earth science research. A key issue is how to strike the appropriate balance between types of research efforts and among different geographical areas, given both financial and time constraints. As with many research-in-

[61] The effort to gather such information (i.e., geologic and geophysical mapping) is often carried out for other purposes by USGS and by private concerns such as the petroleum and mineral exploration industries. The oil and mineral industries are very competitive; companies are often understandably hesitant to make data gathered at considerable expense available to competitors.

FIGURE 2-9: Seismic Hazard Map Development Process



SOURCE: U.S. Geological Survey, 1995.

tensive efforts, it is difficult to quantitatively assess the value of different activities; determining the balance between applied research directed at near-term results and longer term research is a political, not merely a scientific, challenge. Even within the earth science community, tension exists over how to divide resources between expanding the fundamental understanding of quake phenomena and concentrating on mapping hazardous site conditions in areas where damaging seismicity has already occurred.

Decisions on how to allocate earth science research funds should be made in the context of the goals of the earthquake program (discussed in chapter 1). However, several research areas clearly deserve attention:

- **Microzonation.** To better assess the overall risk posed to inhabitants and the built environment, analysis of the potential for strong shaking or ground failure is needed on finer scales. This requires not only the application of improved models of earthquake potential and expected shaking, but detailed mapping of near-surface geology and site conditions. Such microzonation studies have been completed in only a few areas of the United States. Thus, we have an incomplete picture of the probability of significant hazards near populated areas or critical facilities for all but the most intensely studied zones (i.e., the San Francisco Bay area and greater Los Angeles region). Additional emphasis should be placed on microzonation in urban areas and around critical facilities where long-duration, strong shaking is expected.

- **Earthquake potential.** New technologies and practices have enabled significant additions to the body of knowledge required to understand the potential for earthquakes in different areas. Paleoseismology permits more reliable estimates of the magnitude and dates of prior earthquakes, especially in areas where damaging earthquakes have very long recurrence times. This information is essential to gauging the likelihood of future damaging events within a decades-long time frame.
- Satellite-based geodetic techniques have revolutionized the observation and modeling of crustal deformation, which contributes to assessments of crustal stress and strain. This information supports long-term forecasts of earthquake potential. In addition, further enhancements to the scope and accuracy of these techniques could provide the foundation for new imaging methods that, akin to weather forecasting, facilitate reliable earthquake prediction.
- **Geographic focus.** Because of its frequent damaging earthquakes, California is the test bed for the development of many current theories and techniques. However, some of these may not be readily adapted to the Pacific Northwest or to the central and eastern United States. Additional research and data collection specific to these latter areas should be considered to determine what distinguishes the nature of the hazards and to support the application of existing tools.
- **International focus.** Fortunately for those who experience damaging earthquakes, the events are few and far between. This leaves the scientific community at a disadvantage, however, with respect to opportunities to incorporate data into the seismic record and evaluate theoretical models of seismic phenomena. Field investigations and analyses of data from earthquakes that occur outside our borders are crucial to understanding similar U.S. seismic hazards (e.g., subduction and intraplate quakes that have occurred here rarely).
- **Knowledge transfer.** It is essential to maintain efforts to make new knowledge and tools readily available to potential users. In recent years, the earth science research community and NEHRP research agencies have put increased emphasis on knowledge transfer to professionals and the general public. These efforts, although difficult to evaluate, are crucial to ensuring that research results help to accelerate the pace of earthquake mitigation throughout the country.

The Built Environment 3

Earthquake hazards exist throughout the United States. The primary hazard associated with earthquakes is ground shaking, which damages and destroys buildings, bridges, and other structures. Ground shaking also causes liquefaction, landslides, and other ground failures that also damage and destroy structures. This damage can cause massive immediate financial losses, casualties, disruptions in essential services such as water and electricity, and severe long-term economic and social losses. Although the location, timing, and magnitude of future earthquakes are uncertain, there is little doubt that potentially damaging earthquakes will strike U.S. metropolitan areas in the next few decades.

Although earthquakes are unavoidable, the losses they cause are not. This chapter reviews technologies and practices to reduce the societal losses[1] of earthquakes. The focus is on *the built environment*—the buildings, bridges, pipelines, and other structures that bear the brunt of earthquake damage. The chapter first discusses deaths and injuries from earthquakes, focusing on what causes them and how they can be reduced. This is followed by a discussion of buildings—how they are damaged by earthquakes, and what technologies and practices are available to increase the seismic resistance of both new and existing buildings. Technologies for reducing damage to lifelines, such as bridges, water and sewer systems, and energy systems, are then reviewed. Finally,

[1] *Damage* refers to the direct financial costs of earthquakes. *Losses* denotes all of the societal effects of earthquakes, including deaths, injuries, direct financial costs, indirect costs (e.g., those resulting from business interruptions), and social impacts such as increased homelessness. Reducing damage by strengthening the built environment will reduce losses as well.

TABLE 3-1: Major Earthquakes Worldwide, 1980-90

Year	Location	Magnitude	Deaths
1980	Algeria	7.7	3,500
1980	Italy	7.2	3,000
1981	Iran	6.9	3,000
1981	Iran	7.3	1,500
1982	Yemen	6.0	2,800
1983	Japan	7.7	107
1983	Turkey	6.9	1,342
1985	Chile	7.8	177
1985	Mexico	7.9	9,500
1986	El Salvador	5.4	1,000
1987	Colombia, Ecuador	7.0	1,000
1988	Nepal, India	6.6	1,450
1988	Burma, China	7.0	730
1988	Armenia	7.0	25,000
1989	West Iran	5.8	90
1989	U.S.—California	7.0	63
1989	Australia	5.6	13
1990	Iran	7.7	40,000+
1990	Philippines	7.8	1,700
TOTAL			**~96,000**

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

the chapter discusses key research needs for ensuring that the built environment is well protected from future earthquake damage.

CASUALTIES

Deaths

A single earthquake can cause thousands of deaths and tens of thousands of injuries. As shown in table 3-1, in just 11 years—1980 to 1990—earthquakes killed almost 100,000 people worldwide. About two-thirds of these deaths occurred in just two catastrophic earthquakes—25,000 in Armenia in 1988 and 40,000 in Iran in 1990.

The historical record of U.S. earthquake fatalities is less unfortunate. About 1,200 people have died in U.S. earthquakes since 1900 (table 3-2). Most of these earthquakes occurred in regions that were, at the time, sparsely populated; so the low fatality figures for 1900 to 1950 earthquakes are not surprising. However, even those earthquakes occurring since 1950 in heavily populated areas of California have had relatively low fatalities, largely because many of its buildings and other structures are built to resist seismic collapse.[2]

Casualties from future earthquakes are very uncertain. In California, most deaths from future earthquakes will likely be caused by the collapse of older, seismically vulnerable structures. One estimate found that a repeat of the 1906 San Francisco earthquake would cause 2,000 to 6,000 deaths.[3] In the Pacific Northwest and the eastern United States, the potential for large numbers of deaths may be higher than in California. Although the probability of a major earthquake is relatively low, the building stock is more vulnerable, as even new structures often do not use known technologies and practices to reduce seismic damage.[4] One study found that a large earthquake striking the New Madrid region of the central United States would cause 7,000 to 27,000 deaths.[5]

Deaths that occur in earthquakes are due largely to the collapse of structures. In Armenia, most of the deaths were caused by people being crushed under collapsing concrete buildings. All but one of the deaths in the Loma Prieta earthquake were

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

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

[4] As noted in chapter 1, many states in lower risk areas do not have or do not enforce seismic building codes for new construction.

[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. 68.

TABLE 3-2: Major U.S. Earthquakes, 1900-94

Year	Location	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.

due to structural failure.[6] Other earthquakes generally show the same pattern: **people are killed in earthquakes when structures collapse**. 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 earthquake.[7]

Further reductions in fatality levels will come largely from incorporating seismic design principles into new construction (this is not done in many areas of the United States), retrofitting[8] existing structures to improve their seismic resistance, and ensuring adequate fire and emergency response.

Injuries

Earthquake-related injuries, in contrast to deaths, often result from nonstructural damage. Damages

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

[7] Bruce A. Bolt, *Earthquakes* (New York, NY: W. H. Freeman and Co., 1993), pp. 219, 271.

[8] This report uses *retrofitting* to mean adding seismic resistance features, such as bracing, to an existing building to reduce the damage if an earthquake occurs. Some reports use the term *rehabilitation* instead.

TABLE 3-3: Injuries from the Loma Prieta Earthquake, 1989

Source	Percent of Injuries
Hit by falling object	13
Hit by overturning object	11
Thrown into object	18
Fall-related injuries	27
Strained taking evasive action	7
Structural collapse	5
Other	19

SOURCE: M. Durkin and C. Thiel, "Improving Measures To Reduce Earthquake Casualties," *Earthquake Spectra*, vol. 8, No. 1, February 1992, p 99

can occur, and people in or near buildings can be injured, even when there is no structural failure. In Loma Prieta, for example, 95 percent of the injuries did not involve structural collapse (table 3-3). These injuries were caused by falls, being struck by falling or overturned objects, or being thrown into objects.

Some simple, low-cost measures that can reduce these injuries include anchoring bookcases to walls, using chains to secure books in bookcases, securing kitchen appliances to the floor, bolting computers to desks, and tying lights to ceilings.

DAMAGE TO BUILDINGS

When the ground moves in an earthquake, the basement and the first floor will move with it. The top floor, or in a multistory building the upper floors, however, tend to stay put because a building is not perfectly rigid. The movement of the bottom of the building relative to the top puts great stress on the walls. The stress and resulting damage vary depending on the building itself. A simple wood house on a concrete foundation may be knocked off its foundation in an earthquake, because the foundation moves with the ground but the house is left behind. A three-story brick building can be turned into a pile of rubble because the bricks are not rigidly attached to each other; the walls collapse outward leaving the floor unsupported. A tall steel-framed building may show little or no damage, because steel bends and sways to absorb the movement of the lower floors.[9]

The most dramatic, widely feared, and best understood type of damage is *collapse* (also called structural failure)—destruction of an entire building by an earthquake, often killing most of its occupants. A second type of damage is *structural damage*—broken or twisted beams, failure of structural members, and other damages that leave a building standing but often unsafe. In some cases costs of repair approach those of replacement. *Nonstructural damage*—cracks in walls, broken water pipes, broken windows—is rarely life-threatening but is often dauntingly expensive to repair. A final type of damage is *contents damage*—computers sliding off desks, pictures knocked off the wall, dishes smashed, merchandise tossed off shelves in stores, and so on. A useful rule of thumb is that contents are typically worth about 50 percent of the cost of the building

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Earthquakes can severely damage buildings.

[9] However, the 1994 Northridge earthquake resulted in unexpected damage to steel buildings, which is discussed later in this chapter.

TABLE 3-4: Expected Damage to New Buildings That Meet Seismic Codes

Magnitude		Damage (percent of buildings)			
6.0-6.5	7.5-8.0				
Distance to fault (miles)		Minor only	Nonstructural	Structural	Collapse
30	50	10-40	1-5	<1	0
5	40	35-45	10-30	<5	<1
1	30	25-40	20-40	3-10	<2
—	3	5-25	40-70	10-30	<5

NOTE: These estimates are for new buildings that meet the 1991 Uniform Building Code; they do not apply to existing building stock.

SOURCE: Adapted from Earthquake Engineering Research Institute, "Expected Seismic Performance of Buildings," February 1994, p. 15.

itself.[10] Therefore, damage to contents, although rarely life-threatening, can be a significant expense and can cause many injuries as well.

After an earthquake, one typically finds many buildings with nonstructural damage and progressively fewer buildings with greater damage. The degree of damage tends to increase as one moves closer to the fault (see table 3-4).

The type and amount of building damage caused by an earthquake depend on several factors. Liquefaction, in which the soil loses its ability to support weight, can cause a building to sink or topple. Ground-shaking damage will vary depending on the magnitude and frequency of the shaking. In general, long, slow ground movement is more damaging to taller buildings because the ground movement is closer to the building's natural frequency. In contrast, short, rapid ground movements are generally more damaging to shorter buildings. The design and materials used in the building are important as well. Buildings with carefully designed bracing, reinforcements in concrete columns, tightly connected walls and floors, and other seismic design features can ride out even large earthquakes; but those designed without consideration of seismic forces are likely to be damaged. Finally, the material used in construction (e.g., unreinforced masonry, wood, and steel) has a strong influence on a building's response to an earthquake (see box 3-1).

New Construction

Incorporating seismic considerations into the design and construction of buildings is much less expensive than attempting to retrofit an existing structure. Furthermore, if new construction incorporates such features, eventually all buildings will have them as older buildings are demolished. This section reviews the state of the knowledge of designing new buildings to resist seismic forces. The principal tool that determines the seismic performance of new buildings—building codes—is discussed, and several promising new technologies are reviewed.

State of the Knowledge

Numerous technologies and practices for new construction can reduce dramatically the risk of structural failure. These range from relatively simple design features, such as avoiding the use of soft stories (i.e., large open spaces in the first

[10] Risk Engineering, Inc., "Residential and Commercial Earthquake Losses in the U.S.," report prepared for the National Committee on Property Insurance, Boston MA, May 3, 1993, p. 2.

BOX 3-1: Building Materials and Earthquakes

Unreinforced Masonry

Among the most dangerous buildings in an earthquake are those built of unreinforced masonry (URM). These buildings are dangerous for two reasons 1) the floors and roof are often not strongly attached to the walls and therefore the walls tend to collapse outward in an earthquake, and 2) the walls are often not strong enough to absorb the shear forces experienced in an earthquake (masonry is very weak in tension, meaning it has little resistance to being pulled apart). A relatively mild earthquake can turn a URM building into a pile of rubble quite easily. URM is also one of the least expensive building techniques—leading to the unfortunate outcome that lower income groups are often hardest hit by earthquakes. URM buildings are dangerous both to occupants and to those nearby, who can be hit by falling masonry. For example, eight people were killed by falling bricks in the Loma Prieta earthquake; all were killed outside a URM building.[1]

Concrete and Reinforced Masonry

A second type of building—made with reinforced masonry (in which steel reinforcing bars are used for strengthening), concrete frames, or precast concrete—can be dangerous as well, although less so than those built from URM. Concrete frame buildings—typically built in the 1950s to 1970s—are often large, multistory commercial or office buildings. Even when these buildings have walls to absorb some of the stress of an earthquake (called shear walls), the frame itself can fail. Precast concrete is often used for single-story warehouse, light industrial, or commercial buildings. The concrete panels can simply fall away from the building in an earthquake, due to inadequate connections between roof, floors, and walls.

Wood

Wood is often used as a structural material in single-family residences. It is the preferred construction material for smaller buildings in high earthquake risk areas because, unlike concrete, it is flexible and can bend without breaking. In an earthquake, a wood frame building will typically sway and bend, but will not fail. It is rare for a wood frame building to suffer structural collapse in an earthquake. However, wood residences can be damaged, sometimes severely, by an earthquake. Unanchored wood houses sitting on concrete foundations can be knocked off their foundations. Short walls (called cripple walls) that provide support between the floor and the ground can tip, moving the house off the foundation and severing gas lines and utility wires. These dangers can be reduced at reasonable cost by, for example, bolting houses to foundations and bracing cripple walls.

[1] California Seismic Safety Commission, *The Commercial Property Owner's Guide to EQ Safety*, SSC 93-01 (Sacramento, CA. January 1993), p. 8.

floor) in apartment buildings, to the use of complex computer models to assist in the design and location of structural members in a large office building. Although considerable uncertainties exist in building performance under seismic stress,[11] it is generally agreed that **the knowledge exists to design and construct buildings that are unlikely to collapse in an earthquake.** Years of research have yielded a knowledge base that, *if applied properly*, would result in buildings that are unlikely to collapse in an earthquake. However such knowledge may not always be applied

[11] Examples include the steel weld issue (see box 3-1), and recent modeling suggesting that large buildings may be vulnerable to collapse from large ground motions. T. Heaton et al., "Response of a High-Rise and Base-Isolated Buildings to a Hypothetical Mw 7.0 Blind Thrust Earthquake," *Science*, vol. 267, Jan. 13, 1995, pp. 206-211.

BOX 3-1 (cont'd.): Building Materials and Earthquakes

Steel

Steel has long been considered the ideal material for large buildings in high earthquake risk areas. It is extremely strong, durable, flexible, and ductile (i.e., it will bend slowly, rather than snap, if overstressed). A steel-framed building is very unlikely to fail structurally from ground shaking in an earthquake. However, faith in steel as a structurally sound material was shaken by the 1994 Northridge earthquake. In this quake, more than 100 steel-framed buildings—including some under construction—exhibited a severe and costly vulnerability not seen before: the steel beams themselves cracked at or near where they were welded to steel columns. Although none of these buildings collapsed, repair will be very expensive. Furthermore, these buildings were built to modern design standards. Presumably if they are rebuilt to these standards they will be susceptible to the same damage if they are subjected to the same shaking forces. This unexpected vulnerability has international implications because large buildings all over the world are similarly built, and are presumably just as vulnerable to this type of damage.

What has become known as the *steel-weld* problem refers, in most cases, to cracks in steel supporting members at or near welds that joined horizontal beams and vertical columns. In tall buildings, these beams and columns are the backbone of the building. The discovery of cracks in these members usually leads to immediate evacuation due to fear of structural collapse. This problem was discovered in a few buildings in routine post-earthquake inspections; as awareness of the problem spread, cracks were found in more than 100 buildings. Since these cracks were in most cases found only by tearing down walls or other covering material, many were not discovered until inspectors went looking for them.

There is as yet little agreement on why these failures occurred. Fears of financial liability have made all parties sensitive to placing or accepting responsibility Among the possible reasons raised are poor welding quality, poor steel quality, improperly designed connections, and inherent limitations of the beam-column design.

The first proposed technical fix was to reinforce the welds; however, tests of these reinforced welds showed that they too would fail in a major earthquake.[2] A second reinforcing method appears to perform better in preliminary testing, but costs three times as much as a standard connection.[3] Efforts to find effective and affordable solutions are continuing.

[2] "Weld Test Failures Shock L.A.," *Engineering News-Record*, June 13, 1994, p. 9

[3] "Test Results Kick Off More Debate on Steel," *Engineering News-Record*, Sept. 19, 1994, p. 8

properly because of lack of training, costs, and other reasons (these issues are discussed in chapter 4).

There are numerous examples of the ability to build structures that can resist seismic collapse. In the 1989 Loma Prieta earthquake, "well-designed and well-constructed buildings performed well."[12] In the 1994 Northridge earthquake, damage was most severe in older and poorly engineered buildings.[13] The 1995 earthquake in Kobe, Japan,[14] also suggests that current designs can yield build-

[12] National Research Council, *Practical Lessons from the Loma Prieta Earthquake* (Washington DC: National Academy Press, 1994), p. 70.

[13] J.D. Goltz (ed.), National Center for Earthquake Engineering Research, "The Northridge, California Earthquake of January 17, 1994: General Reconnaissance Report," Technical Report NCEER-94-0005, Mar. 11, 1994, p. 3-19.

[14] This earthquake is sometimes called the Hyogo-Ken Nanbu earthquake, to denote the three regions involved.

ings unlikely to collapse. Although the earthquake caused massive losses and more than 5,000 deaths, new structures reflecting current building codes performed quite well.[15]

Our knowledge and implementation of technologies and practices to reduce *nonstructural* and contents damage is poor. Very little research has been done in these areas, and building codes are for the most part directed at protecting life safety by avoiding structural damage.[16] An analysis of residential insurance claims from recent California earthquakes found little correlation between the age of a building and the claim amount: newer buildings, although much less likely to collapse, were just as vulnerable to nonstructural damage.[17]

Building Codes

The knowledge of how to construct new buildings to avoid structural failure is laid out in building codes—detailed documents that summarize consensus design principles. Building codes are the most important policy lever for incorporating seismic considerations into new buildings; some of their key features and constraints are summarized here. A detailed discussion of building codes may be found in chapter 4.

In the United States, the local political jurisdiction typically regulates the design and construction of new buildings through the use of building codes. These codes are intended to ensure the health and safety of occupants. The codes typically set requirements for structural soundness, fire safety, electrical safety, and in some areas, seismic resistance as well. Most local building codes are based on model codes. The three national model codes are: the Uniform Building Code, which has been adopted in part by much of the western United States; the Building Officials and Code Administrators code, generally used in the northeast United States; and the Southern Building Code Congress International, adopted in the southeastern United States. The seismic provisions of these three model codes are based in part on what is known as the NEHRP (National Earthquake Hazards Reduction Program) Provisions.[18] These NEHRP Provisions are produced by an independent organization (the Building Seismic Safety Council) with NEHRP funding.

Codes have strengths and weaknesses that should be recognized. First, building codes are consensus documents. They are the results of negotiation and discussion among interested parties, and they reflect a balance of safety, first-cost, performance uncertainty, and other concerns. Second, codes are intended to provide a minimum, not an optimal, performance level. Although codes are unfortunately often taken as prescriptive, they are intended to define a minimum acceptable level of safety. Third, codes are technologically conservative. The process for updating and modifying codes is complex and time consuming. The result is that new technologies and practices can take years to make it into the model codes. From there, many more years are often necessary before a new model code is adopted by localities. Fourth, codes are intended primarily to prevent structural collapse. They have few requirements for nonstructural damage

[15] See, e.g., National Science Foundation, "Modern Buildings Fared Well in Kobe Quake, According to Preliminary Report," press release, Feb. 23, 1995; and "Kobe High-Rise Rebuilding on Hold," *Engineering News-Record*, Feb. 20, 1995, p. 12. This second reference reports on a post-earthquake survey in Kobe that found more than one-third of pre-1971 buildings were unsafe, while only 6 percent of buildings meeting current codes were unsafe.

[16] "The primary intent (of the Uniform Building Code seismic provisions) is to protect the life safety of building occupants and the general public." Earthquake Engineering Research Institute, *Expected Seismic Performance of Buildings* (Oakland, CA: February 1994), p. 6.

[17] Confidential insurance industry data.

[18] "Two Model Codes Stiffen Protection," *Engineering News-Record*, Jan. 6, 1992, p. 7.

TABLE 3-5: Costs of Seismic-Resistant Features in New Buildings

Building type	Number of cases	Estimated change in construction costs (percent)
Low-rise residential	9	0.7
High-rise residential	12	3.3
Office	21	1.3
Industrial	7	0.5
Commercial	3	1.7
Average	—	**1.6**

SOURCE: S. Weber, National Institute of Standards and Technology, "Cost Impact of the NEHRP Recommended Provisions on the Design and Construction of Buildings," 1985, p. 1-11

or for protecting contents. Finally, they generally apply only to new construction.[19]

Costs of Incorporating Seismic Provisions in New Construction

The cost of incorporating seismically resistant features into new buildings is frequently raised as a barrier to greater use of these features, especially in lower risk areas. These costs are heavily dependent on the design, location, and features of the building, as well as the local costs of labor and materials. Several studies have tried to estimate these costs through the use of representative case study buildings. These studies found that **incorporating seismic resistance features into new buildings increases construction costs by about 1 to 2 percent.**

One study by the National Institute of Standards and Technology estimated the costs of complying with the NEHRP Provisions, relative to building to the existing code. The study found an average increase in *construction* costs of 1.6 percent (see table 3-5).[20] A separate study estimated these costs for new single-family residential buildings. This study found that the costs of complying with the NEHRP Provisions, relative to existing practice, varied from 0 (some houses did not need any changes) to 1.6 percent of construction costs.[21] As in the previous study, these costs would be higher as a percentage of structural costs and lower as a percentage of total costs.

New Technologies

The traditional method of designing a building to resist seismic damage is by strengthening the structure. Although this is often effective at reducing the chances of structural collapse, significant nonstructural and contents damage can still result.[22] Furthermore, it is difficult and expensive to retrofit existing buildings to make them suffi-

[19] It is possible, however, to have building codes apply when existing buildings are extensively modified or expanded.

[20] S. Weber, National Institute of Standards and Technology, "Cost Impact of the NEHRP Recommended Provisions on the Design and Construction of Buildings," 1985, p. 1-11. The choice of denominator in such an estimate is crucial. Construction costs include structural, material, labor, and all other costs associated with actual construction. They do not include land, site development, and other nonconstruction costs. Costs as a percentage of structural costs would be three to four times higher; as a percentage of total costs they would be roughly half of those shown in table 3-5.

[21] NAHB Research Center, "Estimated Cost of Compliance with 1991 Building Code Seismic Requirements," prepared for the Insurance Research Council, Oak Brook IL, August 1992, p. 3.

[22] The contents of a building are typically worth about half as much as the building itself. Risk Engineering, Inc., see footnote 10, p. 2.

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A base isolator cut in half to show its construction.

ciently strong to withstand a major earthquake. Two new technologies that may be able to reduce damages in both new and existing buildings—base isolation and active control systems—are reviewed here, promising information technologies are discussed in box 3-2.

Base Isolation

Rather than the usual method of stiffening a building to resist seismic damage, base isolation in effect disconnects the building from the ground. This allows the ground to move underneath the building while the building stays relatively still. If successful, base isolation can protect both the building and its contents. There are two principal techniques for base isolation:

1. Installing rubber or rubber and steel pads, called elastomeric bearings, between the building and the ground: when the ground moves in an earthquake, the bushing bends and gives; the building, however, stays relatively still.
2. Using a bearing and a concave surface: the building's columns are attached to a bearing or other low-friction material, which in turn sits in a concave surface. In an earthquake, the concave surface (which is attached to the ground) slides around while the building stays still.

There are currently at least 30 base-isolated buildings in the United States, and more than 65 in Japan.[23] Applications of base isolation include new buildings such as the Foothill Communities Law and Justice Center in southern California, opened in 1986, which uses 98 rubber bearings; retrofits to existing buildings such as the U.S. Court of Appeals in San Francisco, originally built in 1905; and other structures such as a water tower in Seattle and art objects in the J.P. Getty Museum in Malibu, California.

Key questions of base isolation are:

- How well does it protect buildings and their contents?
- How does its cost compare to conventional techniques?

Computer modeling and laboratory testing of base isolation suggest that it works quite well. Laboratory tests of a base isolation system built to protect a large statue indicate that the system reduces accelerations 35 to 45 percent at the top of the statue.[24] Computer modeling of a base isolation retrofit to a historic brick tower in Seattle predicted a 75 percent reduction in base shear.[25] A much better test of base isolation would be its performance during a real earthquake. Although no base-isolated structures in the United States have yet experienced a large earthquake, several have been exposed to moderate ground shaking in recent years. Although data are still sparse, it ap-

[23] D. Trummer and S. Sommer, Lawrence Livermore National Laboratory, "Overview of Seismic Base Isolation Systems, Applications, and Performance During Earthquakes," UCRL-JC-115114, August 1993, p. 2.

[24] W. Haak, "Base Isolation System for Large Scale Sculptural Works of Art," in *Proceedings of the Fifth U.S. National Conference on Earthquake Engineering*, July 10-14, 1994, Chicago IL, vol. 1 (Oakland, CA: Earthquake Engineering Research Institute), p. 590.

[25] D. Bleiman et al., "Seismic Retrofit of a Historic Brick Landmark Using Base Isolation," in *Proceedings of the Fifth U.S. National Conference on Earthquake Engineering*, see ibid., p. 616.

BOX 3-2: Earthquake Notification and Early Warning Systems

Additional tools in the mitigation of seismic risks are post-earthquake notification and early warning systems (EWS). Notification systems use automated analysis of seismic data to estimate earthquake location, magnitude, and the geographic distribution of potentially damaging ground motion within minutes of a quake's occurrence. Because electronic signals travel faster than seismic waves through the earth, EWS can warn of approaching ground motion. Initial applications of future EWS include automated shut off of valves and opening of firehouse doors; these actions impose low to moderate costs if the warning is a false alarm. Should 30 to 60 seconds of warning be available, more applications are possible, including turning off computers or halting manufacturing processes and initiating personal safety precautions in schools, homes, or offices.

Development of Earthquake Notification Systems and EWS in California

In 1988, the California Division of Mines and Geology (CDMG) studied earthquake warning systems and their potential benefits and costs in California The agency concluded that, with existing technologies and knowledge of earthquake hazards, construction of an EWS in California would not be justifiable on a cost-benefit basis.[1]

Within three years of this report's release, however, the California Institute of Technology (Caltech) and the U.S. Geological Survey (USGS), Pasadena—with the participation of local governments and the private sector—began providing automated broadcasts of southern California earthquake magnitude and location in near real time. Today, the Caltech-USGS Broadcast of Earthquakes (CUBE) system disseminates this information to the scientific community, public officials, electric utilities, and railroad operators via pagers, electronic access to the Southern California Earthquake Data Center at Caltech, and direct phone lines. Another notification system, the Rapid Earthquake Data Integration (REDI) system, has been operating in northern California since 1993. It uses data from University of California at Berkeley and USGS, Menlo Park, seismographic stations located throughout northern and central California.

Factors contributing to the change of heart toward implementing EWS included

- The National Research Council issued a report that delineated the benefits of real-time analysis of seismological data.[2]
- There were rapid advances in seismic data digitizers and sensors and satellite telecommunications capabilities.

[1] See Richard Holden et al., *Technical and Economic Feasibility of an Earthquake Warning System in California*, Special Publication 101 (Sacramento, CA California Department of Conservation, Division of Mines and Geology, March 1989)

[2] See National Research Council, Committee on Seismology, *Real-Time Earthquake Monitoring: Early Warning and Rapid Response* (Washington, DC National Academy Press, 1991).

(continued)

pears that base isolation systems reduced large accelerations yet had little effect on small accelerations.[26] In one study in Japan, two identical buildings, one with base isolators and one with conventional technology, were built side by side in an active seismic area. The building with base isolators experienced, on average, about 75 percent lower acceleration than the conventional building during a series of moderate earthquakes.[27] There is some evidence, however, that

[26] Trummer and Sommer, see footnote 23, p. 3.

[27] T. Kuroda et al., Argonne National Laboratory, "Comparison of Seismic Response of Ordinary and Base-Isolated Structures," ANL/CP—75357, 1992.

BOX 3-2 (cont'd.): Earthquake Notification and Early Warning Systems

- Increased attention was given to the earthquake threat, facilitated by the 1989 Loma Prieta earthquake in the San Francisco Bay area and the 1992 Landers earthquakes in southern California.
- There was improved perception by the private sector and local governments of the usefulness of ground-motion information and early warning.[3]

REDI and CUBE coordinate to provide complete statewide coverage and to automatically notify the state Office of Emergency Services, Department of Transportation, CDMG, utilities, telecommunications providers, and transportation companies of significant events. Second, strong-motion estimates (for earthquakes of magnitude 5.5 or greater) are broadcast via the paging system and maps of strong-motion distribution are made available on the Internet. After initial source data and strong-motion estimates are released, the systems automatically calculate the seismic moment and moment tensor for the earthquake. This helps to determine which fault planes are involved, to refine magnitude calculations, and to better characterize rupture processes that determine the degree of severe shaking.[4]

Future Directions

Besides developing EWS capabilities, goals for the existing notification systems include reducing analysis time and developing quick damage assessment capabilities to aid in emergency response and aftershock preparedness. For example, university and government researchers are working to include soil amplification and other site effects, and to integrate building inventories into the systems in order to rapidly estimate zones of highest damage and casualties.

In a similar vein, work is under way to develop an automated rapid damage assessment capability intended to alleviate much of the uncertainty, delays, and inaccurate information associated with traditional post-quake intelligence gathering.[5] Data on the built environment are being collected and vulnerability assessment software is being developed that will accept CUBE and REDI data and predict both damage areas and overall impact.

[3] Egill Hauksson, Seismological Laboratory, California Institute of Technology, personal communication, June 28, 1995.

[4] Lind Gee, Seismographic Station, University of California at Berkeley, personal communication, June 28, 1995.

[5] Ronald T. Eguchi et al., "Real-Time Earthquake Hazard Assessment in California: The Early Post-Earthquake Damage Assessment Tool and the Caltech-USGS Broadcast of Earthquakes," paper presented at the Fifth U.S. National Conference on Earthquake Engineering, July 10-14, 1994, Chicago, Illinois, p. 2.

base isolation systems as currently designed may be overwhelmed by large earthquakes that produce very large ground displacements.[28]

The costs of base isolation are not well known. A commonly used estimate is that base isolation adds about 5 percent to the construction costs of a new building. One cost analysis of a new building in southern California found that base isolation would be about 6 percent cheaper than conventional design, with much of the savings coming from eliminating the need for measures to protect computers and other sensitive equipment.[29]

[28] Heaton et al., see footnote 11.

[29] S. Sommer and D. Trummer, "Issues Concerning the Application of Seismic Base Isolation in the DOE," in *Proceedings of the Fifth U.S. National Conference on Earthquake Engineering*, see footnote 24, p. 603.

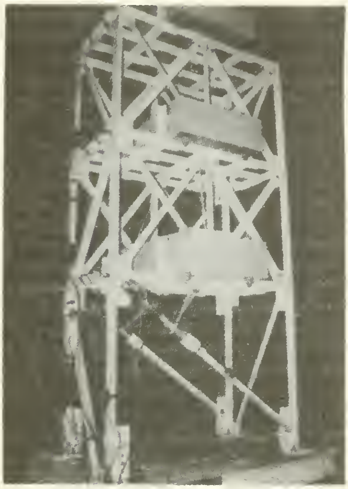
Another study found the life-cycle costs of base isolation to be comparable to conventional technology.[30]

Although these studies suggest that the costs of base isolation are competitive with conventional design, costs are still uncertain. Most applications to date of base isolation have been in buildings where noncost attributes are crucial: experimental buildings, historic retrofits where major interior renovations were impossible, and buildings where continuance of building function after an earthquake was critical.

Active control systems

Another approach to minimizing earthquake damage is the use of active control systems, which detect earthquakes and respond to them. Although many ideas for active control are still at the conceptual stage, some are beginning to be applied in buildings. Perhaps the simplest example of active control is the use of a large weight on the top of a building; the weight is computer-controlled to move so as to counteract the earthquake-induced sway of a building. This technique, known as "active mass damping," is already used in some tall buildings, including the John Hancock Building in Boston, to reduce occupant discomfort from wind-induced building sway.[31] Such a system has been installed in an office building in Japan to resist seismic damage.[32]

A more advanced approach is the use of "active tendons"—electronically controlled actuators that can be instructed to shake the frame of a building so as to minimize earthquake-induced movement. These systems, although still far from commercial application, have the potential to reduce both structural and contents damage by minimizing building movement in an earthquake. They could in theory be used in both new and retrofit applications. An active tendon system has been installed in an experimental building in Tokyo, Japan.[33]



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Active control systems being tested.

Issues affecting the development and use of these systems include:

- *Cost.* Most systems to date have been experimental and designed with little attention to cost. The costs of commercial systems are as yet unknown.

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[30] S. Pyle et al., "Life-Cycle Cost Study for the State of California Justice Building," in *Proceedings of Seminar on Seismic Isolation, Passive Energy Dissipation, and Active Control*, ATC 17-1 (Redwood City, CA: Applied Technology Council, 1993), p. 58.

[31] V. Vance, Langley Research Center, "Active Control of Buildings During Earthquakes," NASA Technical Memorandum, December 1993, p. 3.

[32] "Structures Tuned to the Rhythm of a Quake," *New Scientist*, Feb. 16, 1991, p. 33.

[33] Vance, see footnote 31, p. 5.

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Bracing parapets can reduce damage and injuries

- *Reliability.* These systems will be inactive most of the time, but must work properly when called on. Reliability is critical, and ensuring it will increase cost.
- *External energy requirements.* Active systems require energy, and energy systems can be interrupted in an earthquake. If energy storage is needed, costs will increase.
- *Potential for future applications.* Since a well-designed building is likely to avoid structural damage in all but the largest earthquakes, the value of active control systems will be largely in their ability to reduce nonstructural and contents damage. This value has not been well-quantified.

Existing Buildings

Most buildings in existence today were constructed before our current understanding of how to build them to reduce seismic damage. These older structures were built to earlier, less stringent building codes. This section reviews technologies and practices for reducing earthquake damage in existing buildings. It discusses the costs of doing so and some associated policy issues.

State of the Knowledge

Our understanding of how to retrofit existing buildings to improve their seismic performance has improved in recent years, due in part to NEHRP-sponsored programs, yet numerous knowledge gaps and uncertainties remain. Retrofitting is a more difficult task than new building design for several reasons: the original plans of the building may be missing or inaccurate; it may be necessary to allow the building to remain occupied while it is being retrofitted; owners may want to preserve the appearance of a building (e.g., exterior seismic braces may be unacceptable); and, as always, costs are a concern. Designing retrofit methods that can overcome these obstacles is a continuing challenge.

There are generally agreed-on principles that can guide retrofitting. For example, typical steps to reduce damage include bracing parapets; improving connections among walls, floors, and roofs; strengthening the walls themselves; adding structural framing to support exterior walls; and modifying the building design to reduce asymmetry (symmetric buildings are generally stronger). Work to refine these techniques is ongoing. Its goal is to develop a set of comprehensive guidelines on seismic retrofitting of existing buildings.[34]

Costs of Retrofit

The costs of retrofitting buildings to improve seismic resistance are uncertain, but are generally much higher than incorporating seismic design into new construction. The uncertainty is due to several factors: seismic retrofits are often done in conjunction with other building improvements, such as appearance and fire safety, which makes it

[34] The Federal Emergency Management Agency has published a number of related guidebooks and reports, and plans to complete retrofit guidelines in 1997.

difficult to separate the cost of seismic actions alone;[35] buildings and retrofit techniques differ widely, leading to wide variations in costs; and there is little agreement on the appropriate level of retrofit (i.e., the level of safety a retrofitted building should provide).

Unreinforced masonry (URM) buildings have received the most retrofit attention since they are often the buildings at greatest risk for life safety. Costs of URM retrofits are typically $7 to $18 per square foot.[36] To put these costs in perspective, typical construction costs for new masonry buildings are $40 to $70 per square foot.[37] Combining these estimates yields a range of 10 to 45 percent, with a midpoint of 23 percent: that is, **retrofit of URM buildings typically costs about 23 percent as much as new construction** (although costs will vary considerably). When this is compared with the 1 to 2 percent additional cost of incorporating seismic design into new construction (discussed above), it is clear that retrofitting is much more expensive.[38]

Other Retrofit Issues

Few buildings in the United States have been retrofitted to improve seismic performance, even though they represent a significant risk.[39] Why are retrofits so difficult to implement? Part of the answer is their high cost. As noted above, retrofits of URM buildings typically cost about 23 percent as much as new construction, and costs of retrofits for other building types are comparably high. Perhaps more important, however, is that these retrofits offer little in the way of near-term market benefits (which are typically a function of size, location, amenities, and so forth). Not surprisingly, therefore, the retrofits that have occurred have been largely in response to regulations requiring them (chapter 4 discusses these issues in more detail).

A second issue complicating retrofits is determining the appropriate level of safety. Increased safety comes at an increased cost. For new buildings, the minimum safety level is set by the building code. There is however no such generally accepted code for existing buildings (although guidelines are now available),[40] and requiring them to meet the same safety levels as new buildings would be extremely expensive.

A third issue is how well retrofits work. Data on retrofit performance in earthquakes are rare; however, there is some evidence that retrofitted URMs

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[35] Performing a seismic retrofit may "trigger" other code requirements, such as fire safety upgrades.

[36] Much of the variation can be explained by the level of seismicity to which the building is retrofitted and by the size of the building (larger buildings have lower retrofit costs per square foot). Retrofit costs for non-URM buildings are in the same range—for example, retrofitting precast concrete tilt-up walls is estimated to cost $5 to $19 per square foot. Federal Emergency Management Agency, *Typical Costs for Seismic Rehabilitation of Existing Buildings*, 2nd Ed., FEMA 156 (Washington, DC: December 1994), pp. 1-15 to 1-18.

[37] OTA estimate, based on Federal Emergency Management Agency, *Typical Costs for Seismic Rehabilitation of Existing Buildings*, vol. 2, FEMA 157 (Washington, DC: September 1988), p. 3-72.

[38] Retrofitting, although more expensive than incorporating seismic considerations into new construction, can still be a worthwhile investment if the risk is high (e.g., in an area with a high probability of a damaging earthquake or in a critical building such as a hospital).

[39] For example, a 1994 review of California's seismic risk found, "we still have many earthquake-vulnerable buildings. . . ." California Seismic Safety Commission, "California at Risk," 1994 Status Report, SSC 94-01, p. 1. In the central United States, some states have just begun to identify hazardous structures. 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*, see footnote 24, p. 992.

[40] These guidelines, known as the Uniform Code for Building Conservation (UCBC), are intended not to ensure life safety but to decrease seismic risk. For example, 15 to 25 percent of *retrofitted* URMs located near the epicenter of a major earthquake are expected to collapse in a moderate earthquake. Earthquake Engineering Research Institute, see footnote 16, p. 16. In addition, as noted above, FEMA is working to develop comprehensive retrofit guidelines.

did not perform as well as hoped.[41] Evaluation of retrofit methods is clearly needed.

One major technical issue that makes such retrofits difficult is the analysis of existing buildings. Deciding on a retrofit technique requires an understanding of the strengths and weaknesses of the building as it stands. For many older buildings, however, the original plans are not available; the building has been modified several times since its original construction; and structural details of the building are hidden by nonstructural components. Some work has been done by the National Institute of Standards and Technology (NIST) in applying nondestructive testing techniques, such as sensors that can detect reinforcing rods in concrete, to seismic retrofit problems. The Federal Emergency Management Agency (FEMA) has also sponsored research into "rapid screening methods"—methods to quickly estimate a building's seismic hazard without performing a detailed engineering analysis. These are promising research directions.

DAMAGE TO LIFELINES

Lifelines (i.e., bridges, mass transit systems, overpasses, roads, electric and gas supply systems, water and sewer systems, and telecommunication networks) are often damaged by earthquakes. Much of what has been discussed about buildings applies to lifelines as well:

- most fatalities associated with lifelines are caused by structural collapse;
- the knowledge of how to build new lifeline facilities to minimize structural collapse is available, although this knowledge, for economic or other reasons, may not be used;
- much of the remaining life safety risk lies with existing facilities; and
- existing facilities can be retrofitted, but the costs are high.

There are, however, some key ways in which lifelines differ from buildings. The most important difference is **the high cost of outage**. If a building is damaged, only the functions in that building are lost. If a lifeline is interrupted—even for a brief time—the costs can be massive. The most extreme example would be loss of a water supply system after an earthquake, which occurred in San Francisco in 1906, leading to massive fires. In the longer term, interruptions in water or sewer service can lead to public health problems, breaks in key transportation links can snarl commuting, and the loss of natural gas systems can force otherwise undamaged businesses to close. Thus "success" in lifeline seismic design is often defined as retaining functionality rather than simply reducing damage.

The second major difference is that **lifelines are usually owned and operated by public agencies** (exceptions are electricity and natural gas supply systems, which in most areas are owned and operated by publicly regulated, privately owned companies). Therefore, responsibility for their continued operation, and decisions about their earthquake resistance, often lie entirely with the government.

Bridges

Bridges, overpasses, and elevated highways are often damaged by earthquakes, and the costs of damage to these critical lifelines are high. Catastrophic failure can result in many deaths. Of the 63 deaths in the 1989 Loma Prieta earthquake, for example, 42 were caused by the collapse of one elevated highway.[42] Repair of damaged bridges can be very expensive: the reconstruction of the

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[41] For example, many retrofitted masonry structures suffered severe damage in the Northridge earthquake. Goltz, see footnote 13, p. 3-36.

[42] M. Durkin, "Improving Earthquake Casualty and Loss Estimation," paper presented at the Earthquake Engineering Tenth World Conference, Balkema, Rotterdam, 1992, p. 559.

Santa Monica Freeway in Los Angeles, which was damaged in the Northridge earthquake, cost $29.4 million.[43] Also, interruption of transport services can disrupt the local economy; the 1989 Loma Prieta earthquake caused the partial collapse of the San Francisco-Oakland Bay Bridge, which disrupted the passage of 243,000 vehicles per day.[44]

Bridges can be damaged in several ways, including:

- They can simply be "unseated." Sections of bridges typically sit on horizontal supports, called seats; if the support moves far enough in an earthquake it can simply drop the bridge section.
- The columns holding up sections of a bridge may collapse under the lateral (side) forces caused by an earthquake.
- The soil providing support for a bridge may settle or shift.

Known technologies and practices can do much to reduce the risk of major damage to or collapse of bridges. The primary constraint is the high cost of implementing these technologies and practices, especially when such long-term investments must compete with other public investments for scarce capital.

New Construction

Like buildings, bridges built to current standards of seismic resistance have performed quite well in recent earthquakes. In the Loma Prieta earthquake, only one of the 100 bridges damaged was designed after 1972, when seismic design requirements were revised significantly.[45] Similarly, the two major freeway collapses in the 1994 Northridge earthquake—the Santa Monica Freeway and the I5-SR14 interchange—were due primarily to the failure of supporting columns designed and built before 1971.[46] A total of seven highway bridges collapsed in the 1994 Northridge earthquake; none were built to current codes.[47] The elevated highway that collapsed during the 1995 quake in Kobe, Japan, did not incorporate current knowledge on designing columns to resist seismic damage.[48]

Some design features in new bridges that resist seismic damage include: using continuous spans and thereby eliminating joints that can separate and collapse, using longer seat widths that allow for more horizontal movement without unseating, improving soil strength to avoid liquefaction, designing all bridge components for horizontal loads, and confining (wrapping) columns.[49]

Retrofits

About 345,000 bridges in the United States were built before 1970, with little or no consideration of seismic resistance.[50] Although not all of these are located in areas of seismic concern, retrofitting these bridges remains a major technical, financial, and policy challenge.

Much of the bridge retrofit activity in the United States has been in California. The 1971 San Fernando earthquake in southern California

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[43] "Quake-Damaged Freeway Reopening Ahead of Time," *New York Times*, Apr. 12, 1994, p. A12. About half the cost was a bonus to the contractor for early completion.

[44] U.S. Geological Survey, "The Loma Prieta, California, Earthquake of October 17, 1989—Fire, Police, Transportation, and Hazardous Materials," 1553-C, 1994, p. C18.

[45] National Research Council, see footnote 12, p. 169.

[46] J. Cooper et al., "The Northridge Earthquake," *Public Roads*, summer 1994, p. 32.

[47] I.G. Buckle, National Center for Earthquake Engineering Research, "The Northridge, California Earthquake of January 17, 1994: Performance of Highway Bridges," Technical Report NCEER-94-0008, Mar. 24, 1994, p. 1-1.

[48] Earthquake Engineering Research Institute, *The Hyogo-Ken Nanbu Earthquake*, Preliminary Reconnaissance Report (Oakland, CA: February 1995), p. 44.

[49] Cooper et al., see footnote 46, p. 34.

[50] Ibid.

damaged more than 60 bridges, and led both to revision of standards for new bridge construction and to an ambitious bridge retrofit program. Retrofitted bridges performed very well in the 1989 Loma Prieta earthquake: 350 bridges retrofitted with hinge restrainers were in the area impacted by the quake, and none were damaged.[51] Similarly, retrofitted bridges performed very well in the 1994 Northridge earthquake.[52] Although some hinge restrainers failed, no steel-jacketed column retrofits showed signs of distress.[53]

The technical knowledge of how and what to retrofit is good, but not faultless. The 1989 Loma Prieta earthquake caused the partial collapse of the San Francisco Bay Bridge; this bridge had been retrofitted in the 1970s, and the section that collapsed was not considered vulnerable.[54]

In addition to determining the best technologies and practices for bridge retrofits, funding these retrofits remains a major challenge. The I-880 elevated highway that collapsed in the Loma Prieta earthquake, killing 42 people, was scheduled for retrofit but had not been because of budget limitations.[55] A General Accounting Office survey of state bridge retrofit activity found that very few states had retrofitted their bridges; limited funding was identified as a major barrier.[56]

Water and Sewer Systems

Ground motion and ground failure due to earthquakes can cause water and sewer pipes to break; this can be especially dangerous if fire follows an earthquake. Also, since almost all of these pipes are underground, repair is expensive and time consuming. The 1989 Loma Prieta earthquake caused 748 water supply pipeline breaks; the total cost of repairs was in the tens of millions of dollars.[57] This earthquake also severely damaged San Francisco's auxiliary water supply system.[58] The 1987 Whittier Narrows earthquake caused 17 major water supply pipeline breaks, with the result that water pressure in the system was at half its usual level for two days following the earthquake.[59] The loss of water supply contributed to the severity and duration of fires in the 1995 Kobe, Japan, earthquake.

Recent experiences with the performance of water systems in earthquakes suggest several design principles to reduce future disruptions. The Loma Prieta and Northridge experiences point to the importance of redundancies in water supply systems. In the Loma Prieta earthquake, liquefaction in the South of Market area of San Francisco caused a break in a major pipeline of the city's backup water supply system. Fortunately, other backup systems, including cisterns and a fire boat, were available. Water supply systems should build in redundancies (e.g., multiple pipelines and independent power supplies for pumping) to reduce the probability of the system's being disabled from the loss of any one component. In the Northridge earthquake, a number of water leaks resulted from the breakage of pipes and valves

[51] National Research Council, see footnote 12, p. 168.

[52] Cooper et al., see footnote 46, p. 32.

[53] Buckle, see footnote 47, p. 1-1.

[54] U.S. Congress, General Accounting Office, *Loma Prieta Earthquake: Collapse of the Bay Bridge and the Cypress Viaduct*, GAO/RCED-90-177 (Washington, DC: June 1990), p. 5.

[55] Ibid., p. 2.

[56] U.S. Congress, General Accounting Office, *The Nation's Highway Bridges Remain at Risk from Earthquakes*, GAO/RCED -92-59 (Washington, DC: January 1992), p. 13.

[57] National Research Council, see footnote 12, pp. 138, 146.

[58] "Keeping Lifelines Alive," *Civil Engineering*, March 1990, p. 59.

[59] A. Schiff, "The Whittier Narrows, California Earthquake of October 1, 1987—Response of Lifelines and Their Effect on Emergency Response," *Earthquake Spectra*, vol. 4, No. 2, 1988, p. 344.

where they connect to water tanks. Use of flexible connections that would allow differential movement of pipes and tanks would reduce such leaks. A $17-million evaluation and retrofit of Seattle's water supply system found that elevated water tanks were among the most vulnerable components of the system.[60] Ensuring that such tanks have sufficient anchors and braces will reduce the chances of collapse.

Electricity Systems

In recent earthquakes in the United States, the damage to electricity systems has been relatively minor. Redundancies in transmission and distribution systems, coupled with the inherent flexibility of wires (i.e., compared to rigid pipes), suggests that electricity is not the most vulnerable lifeline. In the Loma Prieta earthquake, several electrical switchyards were moderately damaged.[61] In the Northridge earthquake, about 2 million customers lost electrical power due mainly to substation problems; however, most service was restored within a day.[62]

Fortunately most critical facilities that use electricity—such as hospitals, telecommunications systems, and computer facilities—have backup electricity-generating facilities. However, since most backup systems such as batteries and on-site generators are designed to supply limited power for only a short time (typically hours or tens of hours), longer term electricity system damage can be a serious problem.

Natural Gas Systems

Natural gas is transported through underground pipelines, which are vulnerable to fracture in earthquakes. Resulting natural gas leaks are a dangerous fire and explosion hazard. In the Northridge earthquake, a broken natural gas transmission pipeline caused a fire that destroyed five houses.[63] Analysis of the performance of natural gas transmission pipelines in California earthquakes found that most damage could be traced to pre-1930 welds, which were generally of poor quality. Pre-1930 pipes had a damage rate 100 times that of post-1930 pipes.[64] Modem pipes with high-quality welds are still vulnerable to ground deformation, but are very resilient to damage from traveling ground waves.

Although modem natural gas transmission systems generally perform quite well in earthquakes, leaks and other problems in the distribution system and at or near the service connection are common. In the 1987 Whittier Narrows earthquake, for example, there was only one leak in the transmission system (due to a cracked cast iron pipe) but there were 1,400 leaks on customer property. Three-quarters of these resulted from failures at appliance connections, primarily water heaters.[65] In the Loma Prieta earthquake, the natural gas transmission system was undamaged, but the distribution system suffered extensive damage. Repairs in many cases were made by inserting flexible plastic piping into damaged cast iron pipes.[66] In the Northridge earthquake, 120 mobile

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[60] W. Anton et al., "Seattle Plays It Safe," *Civil Engineering*, August 1992, p. 39.

[61] National Research Council, see footnote 12, p. 142.

[62] Goltz (ed.), see footnote 13, p. 4-11.

[63] Ibid., p. 4-21.

[64] T. O'Rourke and M. Palmer, National Center for Earthquake Engineering Research, "The Northridge, California Earthquake of January 7, 1994: Performance of Gas Transmission Pipelines," Technical Report NCEER-94-0011, May 16, 1994, pp. 2-32, 2-35.

[65] Schiff, see footnote 59, p. 348.

[66] National Research Council, see footnote 12, p. 140-141.

homes were destroyed by fires triggered by natural gas valve leaks.[67]

ACCOMPLISHMENTS AND NEEDS OF FEDERALLY SPONSORED RESEARCH

Accomplishments

Considerable progress has been made in understanding how the built environment is affected by earthquakes and how structures can be designed to reduce structural failure. **NEHRP has done much to expand our knowledge of earthquake engineering.** Although a rigorous evaluation of NEHRP has not been undertaken (and would be very difficult, since much of NEHRP involves research, which is inherently difficult to evaluate), there are numerous examples in which NEHRP-funded programs have had considerable societal benefits.

A 1993 workshop defined some key contributions made to earthquake engineering by the National Science Foundation's funding of research under NEHRP. These include:

- advances in analytical and modeling techniques, permitting seismic structure design on inexpensive computers;
- improved understanding of how structures behave under earthquake-induced stress, which has led to better building codes in such areas 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; and
- improved disaster response planning from social science research that sheds light, for example, on cultural differences in perceptions of disaster.[68]

NEHRP-funded work by NIST, although a small fraction of total program funding, has also addressed some key applied earthquake engineering problems. Examples include testing of base isolation systems, development of methods to evaluate the strength of existing buildings, and evaluation of building retrofit techniques.[69] Additional relevant NIST activities include, for example, development of seismic standards for existing federal buildings and management of a United States-Japan annual meeting on earthquake engineering.

Implementation of this knowledge is a continuing concern; yet there are successes here as well. For example, development of the NEHRP Provisions, a resource document for model codes, and their adoption by model code agencies, is a significant accomplishment. Retrofitting of existing buildings is still a difficult and expensive task, yet FEMA's work in this area has made some progress toward consensus on methods and costs.

These examples of NEHRP successes are not the result of a thorough evaluation of that program, nor do past successes ensure future contributions. However, it is clear that NEHRP has made a significant contribution to improving understanding of how to build structures that will resist seismic damage. (A more detailed description of the current activities of NEHRP agencies can be found in appendix B.)

Future Needs

Knowledge of how to design and build structures so as to reduce earthquake-induced damage has improved considerably. However, the problem is far from solved. The 1994 Northridge earthquake occurred in probably the most well-prepared area of the United States. Nevertheless, it caused 57

[67] Goltz (ed.), see footnote 13, p. 6-5.

[68] National Science Foundation, "Directions for Research in the Next Decade," Report on a Workshop, June 1993.

[69] Richard N. Wright, Director, Building and Fire Research Laboratory, National Institute of Standards and Technology, testimony at hearings before the Senate Committee on Commerce, Science, and Transportation, Subcommittee on Science, Technology and Space, May 17, 1994, on NEHRP reauthorization.

deaths and about $20 billion in losses. Scenarios of future earthquakes across the United States suggest that large losses are likely.

Greater use of existing knowledge, practices, and technologies could reduce these losses. For example, the 1989 collapse of the I-880 elevated highway in Oakland, which resulted in 42 deaths, could have been prevented with the use of known technologies. The implementation (or lack thereof) of these technologies to date has been determined largely by economic, behavioral, institutional, and other factors, not by the state of the knowledge (these issues are addressed in chapter 4).

Nevertheless, improved knowledge could have several benefits. First, although current knowledge of how to build new structures to resist seismic damage is good, it is far from perfect (consider the steel weld failures in new buildings in the Northridge earthquake). Second, many of the financial losses in recent earthquakes resulted from nonstructural and contents damage—areas that have received little research attention. Third, much of the risk of fatalities lies in existing structures, and retrofit methods are still not well developed. Research into improving retrofits could reduce this risk. Fourth, to the extent that economic factors influence implementation, research to reduce costs could lead to greater implementation.

New Buildings

Buildings constructed to comply with today's codes are meeting the goal of providing life safety. Building collapses have been limited largely to older buildings designed to earlier codes. This is a major success, for which NEHRP gets some credit: years of research, and a concerted effort to ensure that the results of this research are incorporated into codes, have resulted in effective new building codes that, if properly applied, will yield a building that is unlikely to suffer structural collapse.

However, several crucial areas of new building seismic design are still not well understood. A new building meeting today's code, although unlikely to suffer structural collapse, will likely suffer expensive nonstructural and contents damage in a major earthquake. This does not indicate inadequate or faulty construction or design. Rather, it reflects the fact that codes are intended primarily to protect life safety by preventing structural collapse and typically have few or no requirements to limit nonstructural or contents damage.[70] It is time for new building seismic engineering research to consider the next problem: **reducing nonstructural and contents damage.** Possible areas of research include:

- data collection and analysis of nonstructural and contents damage from recent earthquakes;
- how to design and build structures to avoid or minimize expensive nonstructural failures such as cracked walls, broken sprinkler systems, and collapsed chimneys;
- analytical methods to measure or predict such damage;
- guidelines for lighting, electrical, water, and other systems design and installation to minimize seismic damage;
- expanding building codes to address nonstructural and contents damage; and
- considering technologies—notably active and passive control—that can reduce these damages.

The major surprise of the 1994 Northridge earthquake was the failure of steel welds. These failures occurred in new buildings and in buildings under construction. Although none of these buildings collapsed, repairing this damage will be very expensive. Since it is not yet clear why such damage occurred or how to prevent it, repairs may

[70] "The primary intent [of the Uniform Building Code seismic provisions] is to protect the life safety of building occupants and the general public." Earthquake Engineering Research Institute, see footnote 16, p. 6.

NATIONAL CENTER FOR EARTHQUAKE ENGINEERING RESEARCH

Testing of URM retrofit methods

not prevent the recurrence of this problem. Research is needed to better understand what caused this failure and how steel frames should be designed, assembled, and modified (in existing buildings) to prevent it from happening again.[71]

Existing Buildings

Much of the risk of collapse and resulting fatalities lies in existing buildings, which do not incorporate current codes and knowledge. Few of these buildings have been retrofitted to reduce risk, and such retrofits have sometimes been expensive, complex, and of uncertain benefit. Additional research is needed to improve understanding of how to best reduce the risk in existing buildings.[72]

The first area of research for existing buildings should be to **better understand the vulnerability of existing buildings.** It is commonly recognized that URM buildings are unsafe. However, for other types of buildings (e.g., precast concrete framed buildings or reinforced masonry buildings), the risk is less well known. Laboratory and field experiments, and collection and analysis of data on how buildings respond during 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**. Many retrofits to date have been expensive and have required extensive site-specific design and analysis. Standardized methods, such as those contained in codes for new construction, would reduce costs. These methods could also allow for multiple levels of safety to accommodate different risk preferences. A third research area is to **extend retrofits from structural damage reduction to nonstructural and contents damage reduction.** The bulk of damage to buildings in recent California earthquakes has been nonstructural and contents damage; retrofit methods to reduce this damage could be very beneficial.

Lifelines

Lifelines are expensive to repair if damaged in an earthquake, and service interruptions are at best inconvenient and at times deadly. Like buildings, lifeline facilities built to current design knowledge generally behave quite well in earthquakes. However, the lack of an accepted national standard for the design and construction of lifelines raises costs and reduces performance. The 1990 NEHRP reauthorization directed FEMA and NIST to work together to develop a plan for creating and adopting design and construction standards for lifelines. The legislation directed the agencies to submit this plan to Congress by June 30, 1992. Although some work has been done on the plan, as of this writing it had not yet 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 risk in

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[71] FEMA is currently using supplemental appropriations funds, passed after the Northridge earthquake, to sponsor research and development related to the steel weld problem.

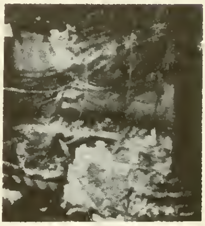
[72] FEMA has an existing buildings program that is addressing some of the issues noted here.

existing facilities, to develop methods to prioritize retrofits, and to develop standardized retrofit methods that can reduce retrofit costs. A goal of preserving functionality, rather than simply minimizing damage, is often appropriate for lifelines. The development of low-cost, easy-to-use procedures to analyze lifelines for weak links would help to ensure their continued function in earthquakes.

Implementation 4

From earth science comes knowledge of earthquake hazards; from engineering, an understanding of how to prepare structures against them. For this knowledge and understanding to actually reduce earthquake losses, however, it must be put into effect. This process, the transformation of research results into real-world measures that will reduce loss of life and property, is referred to as *implementation*.

Implementation can take a number of forms. It can mean the incorporation of engineering lessons into the building practices of a seismically vulnerable region, land-use planning to restrict development of unusually dangerous ground, emergency planning to ensure service or business continuity in the aftermath of a major temblor, or informational outreach programs to inform potential earthquake victims of risks and preventive measures. It is a complex, multifaceted process involving many different players working at many different levels, and as such it is inherently challenging.



In many respects, implementation is the chief bottleneck hindering seismic mitigation efforts in the United States. Research in the earth sciences and engineering has already provided much of the knowledge base needed to prepare against earthquakes: we have a good idea of where earthquakes can occur (at least for the more seismically active areas); we have a sense of their potential severity and probable effects; and where we choose to prepare, we can significantly reduce the likelihood of massive destruction and loss of life. The problem is that we do not always choose to prepare. Despite mounting evidence that truly devastating earthquakes can occur in heavily populated regions of the central United States, Intermountain West, and U.S. East Coast, these regions remain highly vulnerable to future earthquake losses.

Moreover, where we do choose to act (most notably in the state of California), we have focused on issues of life safety and remain vulnerable to devastating economic loss.

These problems—a general lack of earthquake mitigation in many seismically hazardous regions (particularly outside California), and a surprising economic vulnerability in even the best-prepared communities—have drawn attention to how the implementation of seismic mitigation might best be improved.

The emphasis in the National Earthquake Hazards Reduction Program (NEHRP) has traditionally been on the front end of the implementation process (i.e., the gathering and dissemination of research knowledge and recommendations), with the actual execution largely left to state and local authorities, private organizations, and private individuals. As a result, implementation might be improved through better coordination and tailoring of front end efforts to the needs of nonfederal implementers. Alternatively, one might desire to complement existing efforts by having the federal government play a more active implementation role through incentives, insurance, or regulation. All such efforts require an understanding of how the implementation process works, who the chief players are, what their relations are to NEHRP and to each other, and what incentives or disincentives influence their desire or ability to act. Those seeking to improve mitigation efforts in the United States must therefore consider the following:

- How does implementation work in the ideal and in practice?
- What underlying factors reduce implementation success?
- What activities or measures have the greatest impact on implementation success?

These questions are considered in turn. The next section, "The Implementation Process," examines the basic workings of implementation and identifies difficulties that arise in the execution of mitigation measures. Following that, "Factors Affecting Implementation" sets these difficulties in the context of larger motivational problems that complicate the widespread and thorough adoption of mitigation programs. Finally, the section "How Matters Might Be Improved" identifies earth science, engineering, and direct implementation measures that might improve mitigation adoption and execution.

THE IMPLEMENTATION PROCESS

The Voluntary Nature of Earthquake Mitigation

From the perspective of the federal government, the implementation of earthquake mitigation measures is an essentially voluntary process. Federally supported research gives warning of likely earthquake hazards while suggesting possible technical countermeasures, and concerned nonfederal entities decide whether to incorporate those suggestions into state, local, or private hazard reduction schemes.

The origins of this approach lie partly in the unusual scientific climate surrounding NEHRP's conception (a point addressed later) and partly in matters of constitutional authority. That is, although federal funds can guide the course of research, the application of research results takes place primarily through land-use decisions and building codes—authority over which is constitutionally ceded to the states—and through action by individuals and nongovernmental organizations.

To explain in more detail, the essential goals of mitigation are to ensure that buildings and other structures do not collapse, that lifelines and services continue to function, that individuals and organizations are aware of risks and appropriate responses, and (a more recent concern) that economic losses are minimized. The basic tools to accomplish these goals are:

1. building codes for new construction in seismically hazardous areas;
2. retrofit or demolition programs and guidelines to reduce or remove the risk of potentially hazardous older construction;

3. land-use planning or zoning measures to prevent development on particularly dangerous ground (e.g., fault scarps and landslide zones), or to limit such development to nonessential, less vulnerable uses;
4. actions by individuals or nongovernmental groups to reduce nonstructural hazards (e.g., anchoring office equipment), or to initiate measures (land-use, retrofit, seismic-safety standards) beyond those recommended by the government;
5. structural, organizational, or emergency response measures to ensure lifeline survivability; and
6. the collection, processing, and dissemination of information on earthquake risk, mitigation alternatives, and earthquake response to at-risk individuals and organizations.

Of these tools, the first three (which have the greatest impact on reducing catastrophic building collapse and major loss of life) are building and land-use issues, while the fourth is, by definition, private. The federal government has some influence on lifeline survivability via authority over utilities and transportation (and of course on direct federal construction), but its basic role in implementation is currently focused on the last measure—collecting, processing, and disseminating information.[1] This handling of information serves two functions: one is to motivate nonfederal entities toward action by making clear both the risks and the potential losses; the other is to facilitate action by translating research results into readily usable forms (e.g., by incorporating engineering theories into ready-to-use model building codes).

Approaches to Implementation

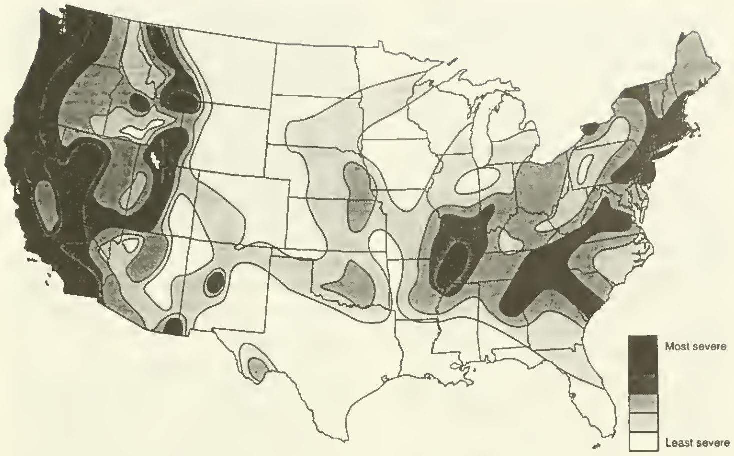
With federal agencies currently playing a primarily informational role, authorities in the state, local, and private sectors are faced with devising their own plans for putting hazard reduction into effect. Because different parts of the country vary in their geology, hazard awareness, economics, political climate, and mitigation history, these plans show a wide range of approaches:

- The overall approach can be regulatory, incentive- or insurance-based, or built on outreach and the media.
- Action can be initiated by states, localities, professional and technical associations, or the private sector.
- In some instances (e.g., hospitals and schools in California), the state takes a direct role in mandating preventive measures. Alternatively, the state can issue voluntary guidelines for local jurisdictions, or it can set performance standards that local authorities must attain.
- Considerable discretion is commonly left to local governments. Where state activity is weak, local authorities sometimes take the lead (indeed, localities in even the most active states are free to adopt more stringent measures than required).
- Finally, important mitigation decisions can be made at a nongovernmental level by regional or local utilities, private businesses, professional societies such as those guiding the training and practice of engineers, organizations governing particularly sensitive institutions such as museums and laboratories, and private individuals.

Despite the variety of mitigation approaches, some common themes recur. In deciding whether and how to guard against earthquake hazards, communities, organizations, and individuals will generally seek to:

1. assess the local level of seismic hazard and local vulnerability to that hazard,
2. decide what changes should be made to the existing and future built environment while ensuring that the benefits of such changes outweigh the costs, and

[1] The federal role could be larger, and options for making it so are presented in chapter 1. However, this discussion reflects the federal role as it currently exists.



OFFICE OF TECHNOLOGY ASSESSMENT, 1995. BASED ON U.S. GEOLOGICAL SURVEY

A community's first step in assessing earthquake risk is to consult large-scale seismic hazard maps; here, the severity of future ground shaking is shown for the continental U.S.

3. devise regulatory, financial, insurance-based, or cooperative tools to put those changes into effect.

Although simple in concept, these steps—particularly the first—are not straightforward to execute. To illustrate the difficulties that arise, the remainder of this section examines how a hypothetical (and unusually thorough) community might approach each of the above steps. For clarity's sake, each step is presented in sequence, with the assumption that conscious, rational thought governs every phase of the process. In the real world, communities or individuals will likely deal with steps simultaneously or in varying sequences, perhaps making decisions on the basis of less-than-formal deliberations; however, the basic problems that arise are the same whether the decisionmaking process is explicit or implicit.

Assessing Hazard, Risk, and Vulnerability

Assessing Overall Hazard—Seismic Hazard Maps

As a first step, this hypothetical community will examine U.S. Geological Survey (USGS) seismic hazard maps[2] to gain a sense of the overall danger. Of concern are:

- the frequency of seismic activity and the likelihood of activity within a future time window,
- the most likely severity of future events, and
- the severity of the worst-case event.

All three points are subject to considerable uncertainty, and all have an impact on the scope and character of the desired mitigation action.

The first point reflects the immediacy of the earthquake threat and can determine the choice of implementation tools. If a community can reason-

[2] There are many types of seismic hazard maps. See chapter 2 for more details.

ably expect a damaging quake several hundred years from now[3]—by which time most or all of its current building stock will have already been replaced—then seismic codes for new construction might suffice for future protection. However, if a major seismic event is expected within the next few years or decades (i.e., within the lifetime of many existing buildings), prudence may dictate more drastic measures such as building retrofit or demolition and replacement. The difficulty is that situations are rarely so straightforward. Because earthquake likelihood is commonly expressed as a probabilistic estimate (i.e., there is a percentage chance of an event during some future time interval) and because building lifetimes vary widely, communities must judge the impact of an uncertain future event on an evolving building stock. As a result, communities must balance the risk of overmitigation (e.g., by tearing down or retrofitting structures that would never have experienced an earthquake) against that of mitigating too slowly and being caught unprepared.

Apart from issues of urgency is the question of earthquake severity: should one prepare for the worst-case scenario, or for the most-likely? The geologic stresses that lead to seismic activity (see chapter 2) can be released by earthquakes of many different sizes, and those preparing for them must choose from a range of predicted calamities. This choice creates problems for those trying to justify the expense of mitigation, for over- and underpreparation can both waste money: overpreparation is expensive for obvious reasons, while an expensively but inadequately prepared building can still be destroyed at a a total loss.

Assessing Risk in Detail

It is tempting to stop the assessment process at the level of the seismic hazard map—knowing the predicted zone of devastation surrounding future earthquakes, one could in theory simply require that all structures within the zone be built to seismically resistant standards.

Real-world costs however make a broad-brush approach impracticable on two counts:

1. In many regions (particularly east of the Rockies) scientific uncertainties mean that enormous portions of the seismic map are marked as potentially hazardous. A broad-brush mitigation strategy can therefore prepare a widespread area for a future earthquake that, if and when it occurs, might strike but a small fraction of the region.[4]
2. Even if predicted earthquake locations are tightly constrained, a broad-mitigation strategy can still be undesirable. Within the general area affected by an earthquake, quirks of local geography and geology will make some localities much more dangerous than others (see chapter 2); these quirks are largely ignored in the preparation of seismic maps. Applying an average level of mitigation to the entire area will thus tend to overprepare some localities while underpreparing others.

For practical and economic reasons, a community will therefore wish to focus its efforts on locations where devastation is most likely. Places subject to ground failure, seismic energy amplification, and other earthquake-related effects (see chapter 2) can experience the bulk of a region's earthquake damage and will call for special attention (or sole attention, if the commitment to mitigation is weak). Because the typical seismic

[3] Such an expectation can never be certain, for there is a certain probability that an earthquake can occur at any time; however, a community in a seismically inactive region may judge its near-term earthquake risk to be too low to warrant drastic action.

[4] This form of overpreparation is particularly troublesome where earthquakes are infrequent, in which case many of the region's buildings will never experience an earthquake during their lifespans.

STEINBRUGGE COLLECTION EERC

Earthquake-induced ground failure (liquefaction) can endanger even the most well-constructed buildings (Niigata, Japan, 1964).

hazard map predicts only the average severity of ground shaking that would occur on an average piece of land, the community will likely have to conduct its own study of local geologic conditions. This sort of "microzonation" assessment is typically far beyond the technical capability of a local government, and although some metropolitan regions have been studied through state efforts or because of special interest on the part of earth scientists, a community will generally have to hire a geotechnical firm to perform the work.

Assessing Vulnerability: Inventory and Damage Estimation

Although one might expect the damage pattern in a community to coincide with the pattern of maximum ground shaking (subject to the microzonation effects noted above), the damage a given building experiences in an earthquake will depend on its design, the type and quality of its construction, and how the building reacts to the particular ground motion characteristics of the earthquake (see chapter 3). Hence, it is not enough to know the local geology and geophysics—one must also estimate how the building stock will respond. Such an estimate requires an accurate inventory of the local building stock and predictive tools relating earthquake damage to building type.

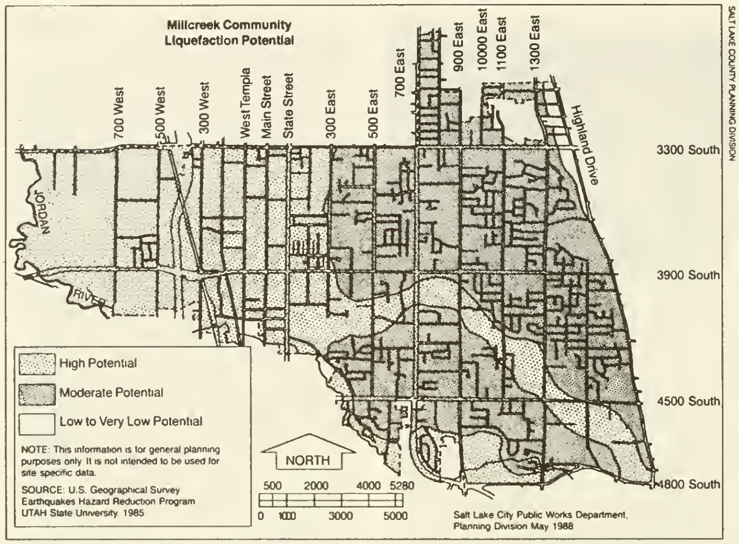
Unfortunately, most communities do not possess workable building inventories. Inventories may simply not exist, they may be outdated, or they may be expressed in terms that are of little use for mitigation (e.g., an inventory developed for tax or urban planning purposes might classify buildings according to function while including nothing about their construction).

A concerned community will therefore probably conduct a building survey to learn what buildings it has, what condition they are in, and where vulnerable structures are located. Again, this is not a straightforward task, particularly when it comes to the most worrisome older structures. That is, it is generally not enough to simply walk down a street and note down what buildings stand along it: a given "old building" might be made of unreinforced masonry; reinforced masonry; or some hybrid, much modified arrangement of wood, stone, metal, or concrete. Therefore, a judgment on its construction and vulnerability may require physical inspection by a specialist.[5]

Finally, having determined its building inventory, the community must relate that inventory to what it knows of the earthquake hazard and come up with an estimate for likely future losses. Ideally, this estimate will include economic loss and casualty figures broken down by building type and geography. Again, such an estimate is not straightforward, because the relation between earthquake damage and building design or construction is as yet poorly understood. However, if it can be done, such an estimate will allow a community to target those areas in which it is most vulnerable, and expend less of its resources in areas that are more robust.

Earthquake loss estimates thus function as a mitigation tool of singular importance. By reducing mitigation costs while increasing the likely

[5] The technical expertise required for such an inventory suggests a possible avenue for federal implementation assistance.



Detailed risk assessment requires the preparation of small-scale seismic zonation maps, in which local geologic dangers are matched to features of the built environment. Here, the potential for liquefaction in a Utah community is overlain on a map of city streets.

benefits, a quantitative loss estimate can increase the effectiveness of current mitigation efforts while making it much more likely for as yet undecided communities to act. Unfortunately, although work is progressing on this front, reliable, consistent estimates are extremely difficult to obtain.[6]

The Office of Technology Assessment (OTA) notes an exceptional lack of quantitative information on expected earthquake losses in specific urban areas of the United States. Loss estimates have been made for certain regions (most notably, metropolitan areas in California), but variations in methodology, scope, assumptions, and even terminology make interpreting or comparing their results difficult. Further lacking are comprehensive data showing the change in expected losses that would result from mitigation—data essential to judging the cost-effectiveness of different mitigation measures. Indeed, many at-risk communities (particularly smaller urban centers in areas outside of California) have little more than a sense

[6] The Federal Emergency Management Agency, under NEHRP, is sponsoring the development of a computer-based loss estimation tool that could allow communities to estimate risk and prioritize risk reduction efforts.

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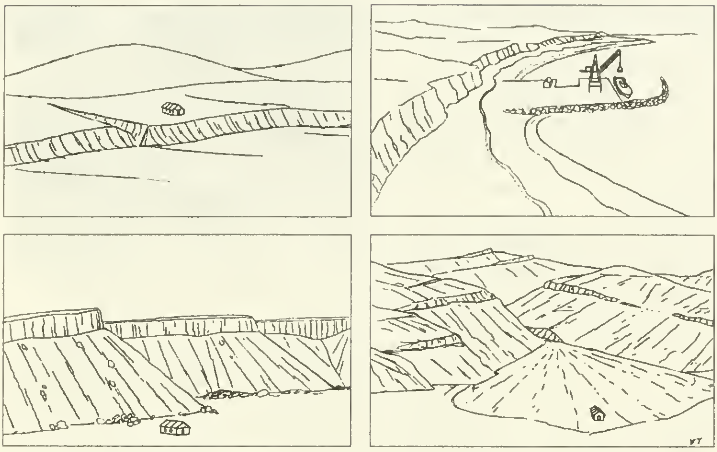

Land-use planning measures are best employed where local geologic conditions create unusually severe hazards (e.g., clockwise from upper left, fault scarps, landfills and land reclaimed from the sea, outwash and alluvial fans; unstable slopes).

that some sort of disaster might happen sometime in the future, and that some sort of preventive action should be taken. Missing are hard data on what are the expected losses, and in what functional and geographic areas will they occur. Without such data, communities can only guess how to respond.

Modifying the Built Environment

Having assessed the risk as well as it can, a community has a choice of mitigation tools with which to proceed. Possibilities include:

- land-use planning and zoning,
- building codes for new construction,
- retrofit or demolition of older construction, and
- systems-related, small-scale, and private activity (including emergency planning).

Although each of these has an impact on both life safety and economic loss, the first three tend to affect life safety issues, while the fourth is more directed toward economic damage.

Land-Use Planning and Zoning

The simplest and most drastic mitigation option is to avoid building things where earthquake hazards are expected. However, such an option is also the least used, and in practice land-use planning generally entails not the outright banning of development, but the tailoring of land use to forms less susceptible to earthquake damage.

Abolishing development on hazardous ground is most acceptable when the risk is clear, the alternatives are poor, and the geographical extent of the expected damage is limited. For earthquakes, circumstances meeting these criteria are relatively rare. The presence of a historically active surface fault rupture offers a possible candidate, in that the likelihood of future fault movement is evident, the engineering options are nonexistent (few structures can resist being torn in two, regardless of their construction), and the most damaging geologic effects occur in a tightly constrained area immediately adjacent to the fault.

However, even where conditions seem right, strict land-use measures such as development bans rarely appear as a mitigation tool. The history of earthquake disasters shows no end of instances where major structures have been built along known faults, even in seismically aware California (e.g., the stadium of the University of California at Berkeley sits atop the Hayward Fault), and with relatively rare exceptions (e.g., the "Faultline Park" in Salt Lake City), such measures are generally unpopular.

The roots of this unpopularity lie in the geographic nature of the earthquake phenomenon. Unlike floods, which typically strike clearly defined parts of floodplains and coasts, the primary earthquake hazard—ground shaking—can be distributed over an area so broad that general development bans become impractical (clearly one cannot halt construction in all of Los Angeles). Even local bans in places of obvious fault rupture or ground failure are often thwarted by a variety of socioeconomic objections (e.g., earthquake faults possess a perverse ability to create potentially valuable real estate with spectacular views). Moreover, typical seismic recurrence intervals of a lifetime or longer mean that bans must be maintained through years or decades of seismic inactivity.

The more likely use of land-use planning is thus in a milder form in which development on dangerous land, though permitted, is restricted to its less vulnerable forms. Thus, for example, a community might identify an undeveloped parcel of land that is subject to liquefaction or landslide, and limit construction to single-story, low-occupancy dwellings, or perhaps to noncritical industrial uses such as warehousing (such is one effect of California's Alquist-Priolo Act, see box 4-1). In this way, land-use planning is used not to prevent earthquake damage outright, but to reduce its direct and indirect impacts. Alternatively, a community might designate high-risk areas as sites

PHILIP R BERKE

Areas of extreme earthquake hazard—such as this fault scarp in Utah—are often attractive locations for development.

requiring special geologic and engineering consideration before building can proceed (as in Utah's Salt Lake County Natural Hazards Ordinance, see box 4-2), thereby ensuring that vulnerably sited structures are more seismically resistant than the norm.

Building Codes for New Construction

With land-use planning reserved for special cases, a concerned community will commonly turn to the most broad-based of mitigation tools—the incorporation of seismic provisions in building codes. By using codes to effect seismically resistant construction, a community can replace the bulk of its building stock over time with one less vulnerable to damage and collapse. Because the approach does not restrict or modify land-use patterns, and because it is relatively inexpensive when applied strictly to new construction (see chapter 3), it can be more politically palatable than a broad-based land-use planning approach.[7] For all these reasons, building codes are perhaps the most popular of implementation options, and are often (erroneously) thought of as the sole tool of mitigation.

[7] In some situations, land-use planning measures can be more politically acceptable than are broad-based building codes (as is the case in Salt Lake County, Utah.). However, such measures are adopted because they are extremely limited in geographic scope, and thus affect a relatively small number of buildings and structures.

BOX 4-1: Land-Use Planning in California: The Alquist-Priolo Act

The classic use of land-use planning to combat seismic hazards is California's Alquist-Priolo Act of 1972. This ordinance, which applies to the local government permit process for new construction, seeks to prevent structures from being built atop active earthquake faults. Its origins lie in the historical prevalence of active fault rupture (see chapter 2) in major California earthquakes, and reflects a belief that buildings and structures cannot be engineered to be resistant to fault motion. In concept, the act represents land-use planning in its purest form, and practical details of the act therefore illustrate basic problems in implementation.

The basic form of the Alquist-Priolo is as follows: the State of California, through its Division of Mines and Geology, identifies active faultlines and defines the land on and immediately adjacent to the faultlines as "Special Study Zones." These zones are typically 600 feet to a quarter mile wide, with the width reflecting the degree of uncertainty over fault location and the amount of secondary fracturing of the ground on either side of the main fault. Those wishing to build within a study zone must submit a licensed geologist's report detailing the existence of active faults near the building site. It an active tault is found, buildings must be "set back" from the fault (the amount of setback ranging from 10 to 50 feet, depending on the nature of the fault). In this manner, buildings are not sited where they are not expected to survive.

Though the Alquist-Priolo is straightforward in concept, practical matters of execution somewhat weaken its impact. The philosophical justification for the act is the government's responsibility to safeguard human life, and the legislation is therefore targeted at occupied structures. Structures occupied less than 2,000 person-hours per year are therefore exempt—an exemption that leaves out most lifeline system components (also exempt are single-family dwellings of wood frame construction, which though not resistant to fault motion, are less likely than other building types to fail in a lethal fashion). In addition, local expertise in geologic matters is required for successful implementation, as direct review authority over the required geologic reports is left to local governments.

Finally, the Alquist-Priolo contains a purely informational component, whereby a buyer of property that lies in a Special Study Zone is supposed to be informed of that fact. This provision of the act has been found to be largely ineffective in influencing buyer behavior.

SOURCE Robert Reitherman, "The Effectiveness of Fault Zone Regulations in California," *Earthquake Spectra*, vol 8, No 1 (Oakland, CA Earthquake Engineering Research Institute, 1992), pp. 57-78

Seismic codes, however, are not a panacea. In practice, their use involves a number of decisions and tradeoffs that can collectively reduce their impact:

- Seismic building codes do not govern every aspect of a community's building stock, but typically focus on specific parts of specific building types (thus ignoring certain aspects of building damage and economic loss).
- Codes cannot serve as a substitute for seismic engineering expertise, and indeed require skill and judgment on the part of their executors.
- Elements of the code adoption process (the steps that translate a seismic engineering recommendation into a specific code at the local level) often reduce code performance from the engineering ideal.
- Effective local enforcement of the code is crucial for reducing risk.

These points are discussed in turn.

Code coverage and philosophy

Although in theory codes can be written so that all buildings in a community are completely built to seismically resistant standards, in practice their application is more selective. Because the application of building codes involves a cost in money and effort, prioritization is necessary, and not all buildings and not all parts of buildings are treated equally.

BOX 4-2: Land-Use Planning in Utah: The Salt Lake County Natural Hazards Ordinance

A region subject to infrequent but potentially sizable earthquakes, the Salt Lake County of northern Utah (an area containing metropolitan Salt Lake City and some 40 percent of Utah's total population) uses land-use planning measures to reduce the impact of future damaging earthquakes. The intent of these measures is not to safeguard the general population, but to reduce the vulnerability of the built environment in unusually hazardous areas. This approach in part reflects the historical lack of seismic activity in the region and the consequent low public awareness of earthquakes and earthquake hazards: while broad-based mitigation measures such as new-construction building codes have engendered active regional opposition (because of feared mitigation costs), geographically limited land-use decisions—which are typically made by a small number of governmental and professional individuals—are less visible to the general public and hence inspire less controversy.

The centerpiece of the county's mitigation strategy is the Salt Lake County Natural Hazards Ordinance of 1989. Significantly, this ordinance does not treat earthquakes in isolation. Instead, seismic concerns are tied in with other natural hazards such as flood, landslide, and avalanche. This tactic allows the less common hazards—of which earthquakes are perhaps the rarest—to be handled by the same procedures that govern the most common, a move that further reduces opposition to the measure while minimizing additional implementation cost.

In outline, the ordinance works as follows: geologic and microzonation studies (some funded through the National Earthquake Hazards Reduction program (NEHRP) and the U.S. Geological Survey) are used to identify particularly dangerous "hazard zones." Those seeking to develop sites within those zones can be required to prepare a special engineering geology study delineating *all* of the local natural hazards and explaining how the hazards will be dealt with (the nature of the hazard zone and the intended use of the site dictate whether a study is called for). The study must then be reviewed by the county geologist, the Utah Geological Mineral Survey, and the Forest Service (in cases of avalanche threat), following which final approval must be obtained by the county's planning commissions.

The hallmark of this ordinance is extreme flexibility—a flexibility cited by county planning staff as crucial to the measure's success. With one exception (no buildings can be placed astride an active fault), the ordinance does not require any specific mitigation action. Developers are therefore free to develop their own mitigation tactics, be it through land-use measures like fault setbacks or through some engineering response. This flexibility is another factor favoring public acceptance of the ordinance, and is felt appropriate to the region's often complicated geology

In turn, a flexible ordinance requires scientific and technical expertise on the part of county officials tasked with reviewing the engineering geology studies (and further demands that reviewers actively use their authority to halt unsatisfactory projects). Earlier incarnations of the ordinance were felt to suffer in effectiveness because this expertise was lacking. In this light, a critical contribution was made to regional mitigation efforts through NEHRP funding of a County Geologist Program from 1985 to 1988. This program, which placed a geologist on the staff of the Salt Lake County Planning Department to improve the geologic review process, was deemed so successful that the county chose to maintain the position following the expiration of federal funding.

SOURCES: Philip R. Berke and Timothy Beatley, *Planning for Earthquakes: Risks, Politics, and Policy* (Baltimore, MD: The Johns Hopkins University Press, 1992), pp. 40-62, and Carlyn E. Orians and Patricia A. Bolton, *Earthquake Mitigation Programs in California, Utah, and Washington* (Columbus, OH: Battelle Human Affairs Research Centers, 1992), pp. 59-60, 69-70

SAN FRANCISCO CHRONICLE

Nonstructural damage—which most building codes do not address—can be considerable

First and foremost, the seismic portion of a building code typically deals only with the building's so-called structural components (i.e., the frames, columns, beams, and load-bearing walls whose failure can lead to building collapse and consequent loss of life). Moreover, the structural components are not necessarily intended to survive a strong earthquake unscathed: if the component is damaged but does not collapse, the code is considered to have done its job. In other words, a code-complying building can "survive" an earthquake (i.e., not collapse and kill people) and still end up a shambles inside and out. This structural emphasis is in part philosophical, since the original intent of seismic codes is to safeguard human life. However, it also reflects a realization that greater levels of building protection entail greater construction costs.

Besides making a distinction between structural and nonstructural components, building codes distinguish in terms of building use. In general, structures that serve critical functions (e.g., hospitals) or house large numbers of people (e.g., schools) are held to a higher standard than are less important, more thinly occupied buildings. These distinctions again reflect the life safety focus of most codes and the great cost of more broad-based mitigation.

Because current codes are thus directed toward life safety, they have only an indirect impact on reducing economic loss. For one thing, the function or occupancy of a damaged building has little direct bearing on its cost of repair or replacement, and a focus on high-occupancy or critical facilities can leave vulnerable many less critical but costly structures. In addition, nonstructural building components such as stairwells, interior walls, ceilings, plumbing, and fixtures can be both dangerous and expensive in their own right (see table 4-1).

Concerns over earthquake-induced economic losses have led some to propose that the focus of seismic building codes be broadened to encompass more than issues of strict life safety. Overall damage reduction could then be pursued through the targeting of nonstructural as well as structural building components, or through the specification of minimum levels of post-earthquake building "functionality." In principle, such changes could be accomplished—although at some additional cost. As noted in chapter 3, however, the knowledge base for this is not yet well developed, and there is the chance that increased code complexity will cause its own problems (e.g., by perhaps aggravating already formidable problems in code enforcement).

Codes: no substitute for knowledge of seismic engineering design

Although a great deal has been learned in recent years about the design and construction of earthquake-resistant structures, most buildings are in fact designed by local architects and engineers far removed from the cutting edge of research. Some way must therefore be found to transfer knowledge and experience from the researcher to the practicing designer.

When resources are abundant, the knowledge transfer process can be direct. If the expense is warranted, one can require that a proposed structure be subjected to rigorous seismic engineering analysis by specialists in seismic design—that is, knowledgeable individuals with a professional obligation to stay abreast of developments in their field. Such an approach has the advantage of directly exposing the design process to individuals

TABLE 4-1: Nonstructural Building Elements Typically Unregulated by Seismic Codes

Exterior elements	Cladding, veneers, glazing, infill walls, canopies, parapets, cornices, appendages, ornamentation, roofing, louvers, doors, signs, detached planters.
Interior elements	Partitions, ceilings, stairways, storage racks, shelves, doors, glass, furnishings (file cabinets, bookcases, display cases, desks, lockers), artwork.
Mechanical, electrical, and plumbing elements	Heating, ventilation, air conditioning equipment, elevators, escalators, piping, ducts, electric panel boards, life-support systems, fire protection systems, telephone and communication systems, motors, emergency generators, tanks, pumps, boilers, light fixtures.
Contents	Electronic equipment, data-processing facilities, medical supplies, blood bank inventories, hazardous and toxic materials, museum and art gallery displays, office equipment.

SOURCE H J Lagorio, *Architectural and Nonstructural Aspects of Earthquake Engineering* (Berkeley, CA University of California at Berkeley, Continuing Education in Engineering, Extension Division, July 1987)

well versed in seismic principles, and is one often applied to major structures such as skyscrapers or nuclear powerplants.

The drawback of the engineering analysis approach is, of course, cost. Cost considerations are such that most buildings in the United States are constructed without the direct input of a seismic engineering specialist, and many of the smaller, more mundane structures (e.g., single-family dwellings) are "unengineered"—that is, designed without any formal engineering input. For such buildings, seismic knowledge transfer can be accomplished through a code. Larger structures are governed by code guidelines that lead nonseismic engineers and architects through the design process; for smaller buildings, the codes offer specific, written requirements for how structures should be built. Such codes, which attempt to incorporate seismic design principles into buildings too small or inexpensive to warrant the involvement of a licensed structural engineer, in theory would require no specialized seismic engineering knowledge. That is, a competent builder or architect unversed in seismic engineering should, by following the code, be able to produce a structure that will not fall down in an earthquake.

In practice, however, the application of codes by competent but seismically unversed individuals will not always be successful. The reason for this failure is the need for flexibility within a building code. That is, although it is possible to write a "cookbook" code that unambiguously spells out exactly how a building should be built, such a code would be unworkable because:

- Successful results are most likely when the overall design of the building is of a type anticipated by the code writer—if the building is innovative or somehow out of the ordinary, the code may simply not apply.
- More fundamentally, a cookbook code does not allow architects and engineers the flexibility to overcome the many unique obstacles that arise in designing buildings and structures.

Because of these concerns, building codes are written so as to give latitude for interpretation while providing some guidance for the inexperienced. Thus it is possible for the seismically inexperienced to rigorously follow a code, cookbook fashion, but still arrive at a vulnerable design.

In short, real-world variety in building design and construction requires that building codes be flexible, and this flexibility in turn requires that judgment be exercised in code execution. Thus **building codes can work as intended only when working designers and building officials pos-**

sess an adequate understanding of seismic design and engineering.

Code adoption process

The preceding discussion presupposes that seismic building codes are actually used in the design and construction of new buildings. How well a code works, however, is of little import if the code is never used. Local and state jurisdictions have considerable discretion over the content of their building codes, and many at-risk areas of the country have chosen to incorporate seismic codes only in part or not at all. The politics and economics of code adoption can thus have a greater impact on seismic safety than do technical issues of code performance.

The process of code adoption is as follows:

- The fruits of research sponsored by NEHRP and other organizations are distilled into a collection of reference documents, most notably:[8]
  1. *NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings*, Federal Emergency Management Agency (informally referred to as the NEHRP Recommended Provisions);
  2. *Minimum Design Loads for Buildings and Other Structures, ASCE-7-93*, American National Standards Institute; and
  3. *Recommended Lateral Force Requirements and Tentative Commentary, Blue Book*, Structural Engineers Association of California.
- These documents, which give suggestions for the stress or force levels that a building must withstand, along with "detailing requirements" that specify the design and construction of critical joints and structural elements, are not building codes. They are instead recommendations that may be incorporated by regional code organizations into idealized "model codes," the most well-known of which is the Uniform Building Code (UBC) of the International Committee Conference of Building Officials, which is used by much of the western United States. (Other model codes include the Southern Building Code Congress International used by southeastern states, and the Building Officials and Code Administrators code used in the northeast United States.)
- Although a model code such as the UBC is in fact a real building code, it does not directly govern the construction of any buildings. Instead, state or local authorities may choose to incorporate it wholly or partly into the codes actually used within their jurisdictions.

There are thus a number of hurdles to be overcome between the creation of a seismic code provision and its implementation. At the highest level, that of the recommended provisions, considerable effort is made to maximize the provision's cost-effectiveness and political acceptability. A successful effort will enhance the provision's acceptability and hence its chances for eventual adoption, but the necessary changes have the effect of making codes minimal, rather than optimal, requirements. At the intermediate level, model code organizations may pick and choose among the recommended provisions in order to meet their members' economic and political concerns. At the end-use level, states and localities will apply their own criteria as well in adopting the model code. **The result can be a wide gap between a NEHRP provision and an actual state or local code.**

Code enforcement: a continuing problem

Finally, the existence of a local building code does little good if it is ignored when the building is designed, and code compliance in a building plan is similarly irrelevant if the actual construction of the building bears little relation to the design. These failings do not imply dishonesty or malicious intent. Simple calculation errors at the de-

[8] Henry J. Lagorio, *Earthquakes: An Architect's Guide to Nonstructural Seismic Hazards* (New York, NY: John Wiley & Sons, Inc., 1990), p. 246.

sign stage, for example, can result in a weakened building, and construction elements such as plywood shear walls can be rendered useless by sloppy nailing. To guard against these and other failings, **a community concerned with seismic safety must invest resources into code enforcement.**

Building code performance therefore requires that plans and the actual construction process be checked by competent inspectors. Unfortunately, few data exist on the performance of local plan- or code-checkers, but anecdotal evidence from California's Northridge earthquake and from Florida's Hurricane Andrew suggest that problems of code execution and compliance result in significant economic losses.[9] The problem is poorly documented but broadly recognized, and represents an area in which improved performance can have benefits beyond simple seismic safety (e.g., improved code enforcement has the potential to lessen losses from wind and fire as well).

In summary, building codes for new construction, although relatively popular and potentially powerful, are no silver bullet: they generally cover only structural collapse, they still require some level of seismic engineering knowledge in order to work well, they might not reflect the latest thinking as captured in model codes or NEHRP provisions, and they must be enforced.

Retrofit or Demolition of Existing Structures

Despite the problems that can beset code implementation, building codes for new construction remain a powerful tool for improving the safety of the built environment. However, when a community has a substantial older urban core and the risk of an earthquake is immediate, the codes may work too gradually. Since the average new building will typically stand for 50 to 100 years before replacement, a community can expect about 1 to 2 percent of its building stock to be replaced each year (more, if the community is expanding and flourishing; less, if it is economically stagnant). Thus if a damaging earthquake strikes within a few decades of a code's adoption, large parts of the building stock will be caught unprepared. A concerned community might therefore consider the most unpopular and contentious of mitigation measures—retrofitting or demolishing vulnerable existing structures (i.e., older structures that do not comply with the latest version of the code).

The unpopularity of this option is manifold. One problem is cost: unlike the case of new construction, in which code compliance adds some 1 to 2 percent to the total building cost, a retrofit/demolition plan can entail enormous expense. Retrofitting an unreinforced masonry building, for example, will generally cost one-quarter the price of a new building (and can in some cases cost much more),[10] while demolition and replacement will of course cost full building value. Such expenditures understandably instill resistance on the part of building owners or anyone else who must bear the expense. In addition, the money spent is not necessarily recouped in the event of an earthquake: retrofits are primarily intended to prevent building collapse, and in some instances a retrofitted building can be just as vulnerable to expensive nonstructural and contents damage as an unmodified structure.

In addition to economic issues, there are considerable objections based on quality-of-life and demographic concerns. Unreinforced masonry buildings, potentially the most dangerous existing buildings, are structures that form much of the urban core of many U.S. cities. They are often prized for two very different reasons: 1) they can embody much of the architectural heritage and character of a city, and 2) they tend to provide most of the low-cost housing used by lower income groups. Demolition is therefore unpopular from both an

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[9] Although current life safety-oriented codes cannot eliminate economic losses, they do—by preserving the structural integrity of buildings—have an often significant impact on direct economic losses.

[10] See chapter 3, "Damage to Buildings," for references and assumptions.

architectural and a housing point of view, while retrofits can lead to rent increases that drive away the original residents. For these reasons alone, city planners may hesitate to take such action, particularly where (as in the central United States) there is great uncertainty about the timing of future earthquakes.

Private, Small-Scale, and Systems Preparation

The three mitigation tools discussed above—land-use planning and zoning, new construction building codes, and retrofit and demolition programs—primarily affect the structural integrity of the built environment. If the primary concern is to reduce loss of life, these tools may suffice. However, they are not enough to curtail major economic losses in the event of a damaging earthquake.

Recent experience (e.g., the 1989 Loma Prieta and the 1994 Northridge quakes) has shown that structural collapses, although spectacular and newsworthy, are by no means the only source of earthquake-related losses. Economic losses also stem from business interruptions; loss of records and computer databases in the service economy; disruption of roadways, utilities, and other lifelines; and widespread, noncatastrophic damage to residential and commercial structures throughout the earthquake region. Although it is difficult to quantify the effect of these losses (particularly in the case of indirect economic damage), their significance is suggested by one estimate of direct residential losses in future earthquakes. This estimate implies that catastrophic building failure, which is what codes and retrofits are designed to prevent, will be responsible for less than one-tenth of California's future bill for direct earthquake losses.[11] Even neglecting the potentially significant issue of indirect losses (i.e., those pertaining to the disruption of business and services), we thus find that traditional mitigation tools of land-use planning, retrofits, and building codes can be largely undirected at reducing the economic impact of a major earthquake.

To mitigate against economic damage, a community must therefore encourage a varied assortment of measures that are collectively referred to in this report as "private, small-scale, and systems preparations." These are measures adopted primarily by individuals, corporations, and utilities to reduce the economic losses caused by various nonstructural failures. The distinction between these measures and structural tools is somewhat arbitrary (e.g., structural building codes can help reduce nonstructural damage, and lifeline-related losses ultimately stem from the failure of bridges, dams, and other structures). However, as a group the measures are ones requiring motivation, careful thought, and tailoring of strategy by individual end users, and as such are not well suited to broad-brush, mandated approaches.

Examples of such measures are:

- Encouraging individual developers and building owners to adopt design and construction techniques that exceed code requirements. As noted earlier, codes serve as a minimum standard, and future structural and nonstructural damage might be averted if a structure is built to a higher level of performance.
- Developing, *before* a damaging earthquake, contingency plans for rerouting traffic, dispatching emergency crews, establishing alternative water, power, and supply sources, and otherwise taking action to reduce post-earthquake indirect losses. Such activity, which requires considerable time, expertise, and coordination, can be taken by both governmental and private entities.
- Motivating individuals, businesses, and organizations to systematically identify their own earthquake vulnerabilities and to take appropriate action. These actions can range from securing bookshelves and waterheaters by homeowners, to elaborate efforts on the part of

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[11] Risk Engineering, Inc., "Residential and Commercial Earthquake Losses in the U.S.," report prepared for the National Committee on Property Insurance, May 1993, p. 17.

businesses, hospitals, schools, museums, and utilities to establish redundancies of power, services, computer databases, and the like.

Success in these efforts can work greatly to reduce the damage, injuries, and general chaos that may accompany earthquakes. The difficulty is that such efforts require diligent action on different fronts by different players, many of whom may care little about mitigation. Complicating matters is that most of these efforts require for their success that other measures be successful as well. For example, computer backups do little good if the computer resides in a building that collapses, and a single unsecured water heater can set an otherwise diligent neighborhood ablaze. Success thus depends on the community possessing a broad, active, and sustained level of public interest in mitigation.

Devising and Fostering Action

Once a community has decided on its choice of mitigation measures, it must put those measures into effect. The simplest action is to require (through regulation or mandate) that certain steps be taken. Such an approach, however, risks alienating the affected constituency (particularly in cases such as building retrofit or demolition, where high mitigation costs might be borne by a small group of individuals). Thus, in practice, many communities have chosen to develop alternative implementation strategies using financial or zoning incentives for mitigation, or (more weakly) through notices and disclosure laws warning potential renters or buyers of a building's noncompliance. Experience has generally shown that for success to be achieved, implementation schemes must be tailored to the particular political, socioeconomic, and geological conditions of a specific at-risk community, and that great pains must be taken to involve (as much as is possible) a broad-based constituency. Some possible approaches are illustrated in boxes 4-1 through 4-4. One potentially powerful implementation tool—the use of insurance to encourage the adoption of seismic mitigation—is not discussed because of a lack of historical experience.

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Many earthquake losses cannot be eliminated through codes or other governmental measures, but require that individuals take steps to prepare.

FACTORS AFFECTING IMPLEMENTATION

In the preceding section, some of the practical difficulties that arise in putting mitigation tools into effect are discussed. This section focuses on several underlying issues that more fundamentally influence implementation success.

Basic Problems

Communities interested in mitigation can encounter many frustrations in determining their level of seismic risk, in estimating their vulnerability to that risk, in assessing the short- and long-term economic consequences of mitigation, and in putting mitigation tools into effective action. Such difficulties arise even in the relatively straightforward process of improving life safety

BOX 4-3: Seismic Retrofit in Los Angeles, California

After California's San Fernando earthquake of 1971, in which buildings of unreinforced masonry (URM) construction experienced substantial damage, the nearby city of Los Angeles began considering ways of safeguarding its own URM building stock. Action was initiated in February 1973, via a city council motion to study the feasibility of seismic "building rehabilitation," but eight years would pass before the landmark Los Angeles Seismic Ordinance finally became law. The twists and turns on the road to this ordinance—and the at times surprising impact it has had on local land-use patterns—illustrate some of the issues that can arise in the implementation of seismic retrofit programs.

Initial Action

Seismic retrofit action in Los Angeles was prompted by the San Fernando experience, by the 1971 passage of an earthquake hazards reduction ordinance in nearby Long Beach, and by the recognition that the city possessed many thousands of old, potentially vulnerable URM structures, many of which were extremely densely occupied. Concerns centered on life safety issues, with little priority given to minimizing earthquake-induced economic losses, and early attention focused on high-density, public-assembly buildings such as churches and movie theaters. This philosophy of targeting a select group of high-vulnerability structures quickly ran afoul of such community groups as architectural historians, who feared the demolition or visual modification of many of the city's historical landmarks, and groups such as the Association of Motion Picture and Television Producers, which felt that seismic ordinances would force the bankruptcy and closure of many marginal theaters (particularly since the proposed ordinances were combined with compliance requirements for structural, electrical, and fire safety codes from which the buildings had hitherto been exempt).

Vigorous community opposition to the proposed ordinances therefore led to the holding of public and city council meetings from 1974 through 1976. Following these meetings, it was decided to target only the most potentially catastrophic buildings: pre-1934 URM assembly buildings that could contain over 100 occupants in the assembly areas. Because of continued concern over the financial implications of seismic retrofit (contemporary estimates placed retrofit costs at amounts comparable to the cost of an entirely new building), recommendations were also made that the retrofits be in part publicly funded by federal and state grants (for which lobbying efforts were initiated), low-interest loans, or tax incentives.

Work on establishing forms of financial assistance proceeded through 1976, but progress was impeded by a combination of legal and engineering difficulties. One problem was that governmental assistance to churches or other sectarian-use buildings was deemed unconstitutional; another was a growing realization that very little was known about the true costs of seismic retrofit.

After three years without progress, an interim proposal in October 1976 suggested that the 14,000-odd buildings to be targeted by the eventual ordinance be prominently signposted as seismically hazardous. By posting such information, the city hoped to invoke market forces for mitigation (by reducing market demand for vulnerable structures) before the start of seismic retrofit. This information-based proposal was strongly attacked by a host of citizen groups, among them the Hollywood Chamber of Commerce, apartment house owners, owners of commercial properties, and private attorneys. All expressed outrage and concern over possible effects on rents, property taxes, insurance rates, real estate sales, bank financing for renovations, lost jobs, and local economic development. Faced with this overwhelming opposition, the city tabled the proposal and redirected its efforts to the core components of the ordinance.

BOX 4-3 (cont'd.): Seismic Retrofit in Los Angeles, California

At this point in the controversy, studies were commissioned to determine the economic and social impacts of different proposals. Key issues included the breadth of the eventual ordinance (e.g., it was decided early on to cover a wide range of commercial and private building types, but to exempt single-family residences); the amount of time a building owner would be given to comply; the rapidity with which the program would be phased in and the prioritization given to different buildings and building types; and the type, availability, and impact of different financial assistance schemes. By 1978, these studies had identified specific concerns for the city council to address, among them: a continued lack of accurate retrofit cost estimates; a real possibility of substantial insurance premium hikes in the region, a significant likelihood of rent increases that would displace low-income residents, an insufficient municipal tax base for financial assistance (Proposition 13 had recently been passed), and an expectation that some businesses displaced during retrofitting would leave the city entirely

Final Passage

With most of the concerns identified in the studies of 1977 to 1979 revolving around the economics of seismic rehabilitation, a breakthrough eventually occurred when three old URMs were found to stand in the path of a street-widening program. The city was persuaded to donate the three buildings for tests on the true costs of seismic retrofits. These tests, which were completed by 1980, showed retrofit costs to represent only about 20 percent of replacement costs—far less than had previously been suggested—and in so doing significantly weakened the economic objections to the proposed ordinance.

At last, after more lengthy debate, a seismic safety ordinance was formally adopted by the city on January 7, 1981—almost a decade after the initial impetus of the 1971 San Fernando earthquake. In its final form, the ordinance targeted all commercial URM structures and all residential URM buildings housing five or more dwelling units. After being notified by the city, owners of targeted buildings would have three years in which to bring their structures up to standard (this standard represents some 50 to 70 percent of the 1980 Los Angeles requirements for new construction). Buildings not brought up to standard would be demolished To ease the impact on building owners and to facilitate bureaucratic execution, the ordinance allowed a one-year compliance extension should wall anchors (see chapter 3) be installed within the first year, and used a staggered notification schedule based on building type. Essential and high-risk facilities were to be targeted first, with lower risk structures to be dealt with later, as a result, some owners of low-risk buildings were not to receive official notification until 1988

Impact of the Ordinance

From a seismic mitigation viewpoint, the Los Angeles Seismic Ordinance can be viewed as a success. Though the process has been more protracted than proponents might wish, a seismically vulnerable urban core is being prepared against the near-certainty of future earthquakes in the region. Should a damaging earthquake strike Los Angeles in the near future, it is extremely probable that many lives will have been saved by this measure. However, the ordinance has also generated side effects Most notable has been the loss of low-cost housing, arising from owners raising rents in an attempt to recover out-of-pocket retrofit expenses. In addition, architectural and historic preservation has suffered—not because of building demolition (generally forbidden by historic building codes), but because of partial demolition, the removal of architectural ornamentation, and the filling in of windows.

(continued)

BOX 4-3 (cont'd.): Seismic Retrofit in Los Angeles, California

Perhaps the most surprising development has been a change in the overall appearance of some URM-lined streets, a change stemming from an unexpected interaction between seismic and fire safety regulations: noncompliance with existing fire safety codes has led many URM owners to close the upper floors (thus avoiding the cost of code compliance), and bring to compliance only the higher rent street level for use by commercial establishments (this partial vacancy is possible because fire safety codes need apply only to the occupied parts of a building). Because seismic retrofit must be applied to entire buildings—which means that vacant, nonproductive floors must be strengthened along with floors that are actually occupied—many of these URM owners have chosen to remove the upper floors entirely, leaving behind only single-story structures. Aside from aesthetic considerations, such removal further reduces the potential low-cost housing stock within the city's urban core.

WILLIAM SPANGLE AND ASSOCIATES, INC

An unexpected side-effect of the Los Angeles seismic retrofit program was the partial demolition and conversion of multistory buildings into low, single-story structures.

SOURCES: Daniel J. Alesch and William J. Petak, *The Politics and Economics of Earthquake Hazard Mitigation* (Boulder, CO: University of Colorado Behavioral Science, 1986), pp. 57-82, and Martha B. Tyler and Penelope Gregory, *Strengthening Unreinforced Masonry Buildings in Los Angeles: Land Use and Occupancy Impacts of the L.A. Seismic Ordinance* (Portola Valley, CA: William Spangle and Associates, Inc., 1990).

through building codes. When the goal is to reduce economic losses—which requires a much more comprehensive effort by both governmental and nongovernmental entities—the uncertainties are even greater.

Given these uncertainties, it is perhaps not surprising that many communities have encountered difficulties in implementation. The problems are not insuperable in California—where earthquakes are frequent and severe enough to foster a desire for action—but even there one finds substantial variations in preparedness among different communities, and substantial difficulties persist in areas of retrofit and private or organizational activity. Outside California, matters are generally worse: in many hazardous regions, a relative lack of historical seismic activity produces a consequent lack of concern, so that even basic mitigation efforts languish.

Administrative Difficulties

In response to this inactivity, NEHRP has sponsored social science research on how and why communities act or fail to act. This research has shown that a number of forces conspire to weaken community will. Some of the difficulties stem from poor experience with existing mitigation ef-

BOX 4-4: Voluntary Retrofit in Palo Alto, California

While several communities in southern California have attempted mandatory retrofit and demolition programs to reduce the seismic vulnerability of urban centers (see box 4-3), the northern California city of Palo Alto has recently introduced a wholly voluntary, information- and incentive-based seismic retrofit program that is showing some early signs of success.

The origins of Palo Alto's voluntary program lie in two failed attempts at introducing mandatory, Los Angeles-style requirements. The first, a 1982 proposal targeting 250 unreinforced masonry, tilt-up (see chapter 3), and other vulnerable structures, succumbed to strong opposition from affected building owners and tenants. Following the defeat of this ordinance, the Palo Alto city council formed a broad-based citizen's Seismic Hazard Committee representing a range of public and private interests. This committee was intended to devise a second hazard mitigation plan that would reflect the concerns of the general community. However, the creation of the committee had the effect of greatly heightening community awareness of local seismic risk and hazard, with the consequence that the second proposal (in 1983) was far stronger than the first. This, too, went down in defeat—in part because of an inflexible retrofit timetable, and in part because proponents of the measure were hampered by extreme uncertainties regarding building vulnerability and the potential economic impacts of the ordinance. In light of these uncertainties, it was suggested that a voluntary program be instituted, one that would allow building owners to judge whether retrofit was economically justified, and one that would permit flexibility of approach and timing.

In 1986, a seismic ordinance was therefore passed in which no buildings were mandated for retrofit or demolition. The provisions of this ordinance are as follows: at-risk structures (particularly those with high occupancy) are identified and their owners given official notification. Following notification, building owners are required to contract with a structural engineer to evaluate building vulnerability and to suggest appropriate engineering fixes. Owners do not have to carry out the suggestions; however, they are required to inform building occupants in writing that an engineering study has been performed and that the results have been publicly filed with the city. In concert with the city's relatively high level of seismic awareness (fostered by the high education level of the citizenry, the work of the Seismic Hazard Committee, the presence of well-placed mitigation advocates within the local government, and extensive media coverage of earthquake disasters elsewhere), this notification is intended to affect rental and real estate prices in the city's highly competitive market. A March 1988 review of the program suggested that this market incentive is working as planned. To further increase the incentive, the city has also offered a zoning bonus, in which seismically upgraded buildings are allowed greater floor areas than is otherwise the norm. This bonus (again in concert with the city's strong economic health) also appears to be effective, to the extent that building owners who are unaffected by the program have sought (unsuccessfully) to obtain the bonus by having their own buildings included.

SOURCE: Philip R. Berke and Timothy Beatley, *Planning for Earthquakes: Risks, Politics, and Policy* (Baltimore, MD: The Johns Hopkins University Press, 1992), pp. 63-81.

forts, which can suffer at the state and local level from:

- a lack of scientific and technical information in a form that local governments and private industry can easily use;
- overly stringent reporting, oversight, and approval requirements; and
- tasks that require more staff resources than are available (typically, implementation duties are assigned to but one or two persons in a state office).[12]

[12] VSP Associates, Inc., "State and Local Efforts To Reduce Earthquake Losses: Snapshots of Policies, Programs, and Funding," report prepared for the Office of Technology Assessment, Dec. 21, 1994.

More fundamentally, existing state and local efforts can suffer from a lack of hard information on earthquake risks and potential impacts. A recent survey of state activities has shown that **across the risk spectrum, studies of historical earthquake activity and assessments of current vulnerability are the two types of information essential to raising awareness, understanding, and commitment to seismic safety.**[13]

The Role of Advocates

Despite the difficulties that beset state and local mitigation efforts, considerable progress has been made by a number of concerned communities.[14] In many instances, this progress arises from the presence of well-placed mitigation "advocates"—energetic, often exceptional individuals in state or local government who adopt and push the cause of mitigation. Such advocates do not work in isolation. Rather, they can act as catalysts for action in communities where local political and socioeconomic conditions are conducive. Although their presence is not essential for action to occur, advocates can have an impact completely out of proportion to their numbers. Indeed, a number of cities owe the bulk of their mitigation progress to a handful of such individuals.[15]

Political Will

The importance of individual advocates, however, points out a larger problem besetting NEHRP: earthquake mitigation advocates (successful or not) are generally in the position of encouraging activity for which there is little initial enthusiasm. This reality has stem implications for efforts to reduce earthquake-related economic losses. While a few well-placed advocates can help convince governments to adopt building codes or land-use planning, they are less likely to create the groundswell of public action needed to substantially curtail future economic losses.

OTA's review of the implementation process has shown that effective mitigation depends on competent, committed action by a host of different individuals. This need is especially apparent in the case of private, small-scale, or systems-related efforts, which require that people design and implement their own mitigation schemes. Yet it is also true for the relatively straightforward use of building codes (i.e., an effective building code, adopted in full by the state or local authority, interpreted by engineers trained in seismic design principles, and enforced by experienced plan and code checkers working with the support of the local community) (see figure 4-1). To some extent, the many players in the chain can be persuaded or forced into action (at least for a while), but as a whole, implementation is greatly enhanced if there is an evident and sustained political will to support mitigation. Such is often not the case in the United States.[16]

Perceived and True Danger of Earthquakes

Nonfederal support for seismic mitigation suffers in part from the relation between earthquake risk and geography. At the federal level, interest in earthquake mitigation is sustained by a high prob-

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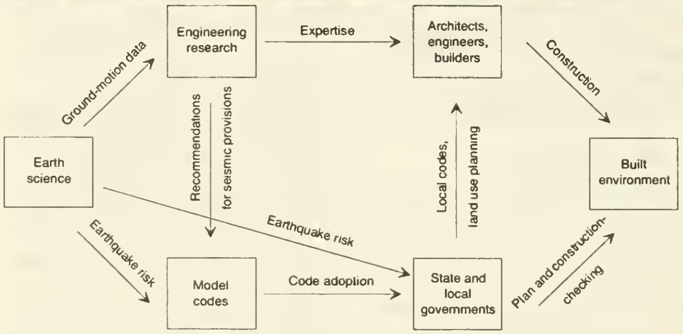
[13] Ibid.

[14] The report prepared for OTA indicates that California, Kentucky, Missouri, Utah, Arkansas, Washington, and Oregon devote particular attention to the formulation, adoption, and implementation of major policies. Ibid.

[15] Joanne M. Nigg, "Frameworks for Understanding Knowledge Dissemination and Utilization: Applications for the National Earthquake Hazards Reduction Program," *A Review of Earthquake Research Applications in the National Earthquake Hazards Reduction Program: 1977-1987*, Walter W. Hays (ed.) (Reston, VA: U.S. Geological Survey, 1988), pp. 13-33; Philip R. Berke and Timothy Beatley, *Planning for Earthquakes: Risk, Politics, and Policy* (Baltimore, MD: The Johns Hopkins University Press, 1992), pp. 32-34; and U.S. Geological Survey, *Applications of Knowledge Produced in the National Earthquake Hazards Reduction Program: 1977-1987*, Open File Report 88-13-B (Reston, VA: 1988), pp. 20-22.

[16] Peter H. Rossi et al., *Natural Hazards and Public Choice: The State and Local Politics of Hazard Mitigation* (New York, NY: Academic Press, 1982), pp. 40, 71.

FIGURE 4-1: Implementation Steps and Key Players for the Application of Seismic Codes



NOTE Steps and players will differ for other types of mitigation measures

SOURCE Office of Technology Assessment, 1995

ability of damaging seismic activity occurring within federal jurisdictional borders. To the extent that California bears the largest share of the country's earthquake hazard, California state interest in earthquakes is also reasonably strong (it is not coincidental that California's mitigation efforts frequently surpass those of the federal government). For the rest of the country, however, the risk[17] of earthquake activity in any one state is considerably less than the nationwide risk borne by the federal government, and everywhere the local risk declines further when one considers the smaller governmental or organizational units. At the extreme is the plight of the individual building owner in a region such as the Northeast. This individual owns a structure that might never experience a damaging earthquake. If an earthquake occurs, the building may or may not collapse. If it does collapse, it is not certain that retrofitting would have saved it.

In short, while the federal government may have a legitimate interest in encouraging all building owners in the country to consider retrofits (on the assumption that at least some of those retrofits will do some good), an individual owner may see very little reason to embark on a costly action whose benefits are long term and uncertain. The owner's lack of interest may be based on a very rational analysis of costs and benefits, but can also be influenced by the short time horizon frequently observed in analyses of consumer decisionmaking (sometimes expressed as a high consumer discount rate), an influence that has been well documented in issues of energy efficiency,[18] and which has relevance to hazard mitigation.[19]

[17] *Risk* is used here as total exposure or potential for damage in an earthquake.

[18] See, e.g., U.S. Congress, Office of Technology Assessment, *Building Energy Efficiency*, OTA-E-518 (Washington, DC: U.S. Government Printing Office, May 1992), chapter 3.

[19] H. Kunreuther, "The Role of Insurance and Regulations in Reducing Losses from Hurricanes and Other Natural Disasters," *Journal of Risk and Uncertainty*, forthcoming.

With perceived risk at the individual level often very low, one can attempt to increase it through skillful use of the media and educational outreach. That the media can have significant impact on earthquake awareness is unquestioned, and history has shown that extensive media coverage in the aftermath of a damaging earthquake creates a temporary "window of opportunity" for rapid mitigation progress.[20] The importance of these windows—and the unpleasant reality that mitigation progress can easily stall after the window closes[21]—has prompted research on how one may best create a permanent perception of risk. Results have thus far been mixed—for example, some studies show that people already overestimate the risk of rare events such as earthquakes,[22] while others suggest that low probability risks tend to be ignored.[23]

Role of NEHRP

Given the general lack of sustained public support for mitigation, why does NEHRP depend so heavily on the unforced adoption of mitigation measures by nonfederal entities? In large part this dependence stems from the scientific circumstances that surrounded the program's birth. In broad terms, NEHRP was created during a period of optimism over the practicability of accurate earthquake prediction, and its original program mission (which specifically cites prediction as a goal) reflects that optimism. At the time of NEHRP's founding, the earth sciences had just emerged from a sweeping and profound revolution, one comparable to Darwin's theory of evolution in its scope, impact, and ramifications. This revolution was the advent of modern plate tectonic theory—a conceptual picture of the world that, through the 1960s and early 1970s, succeeded in tying together a host of previously unexplained and seemingly unrelated phenomena from across the earth sciences. Seismology—the study of earthquakes and earthquake-related phenomena—played an integral role in the development of plate tectonic theory; in turn, plate tectonics offered a simple unifying framework for understanding why, when, and where earthquakes should occur. The decade of the 1970s was thus one of extraordinary excitement in the earth sciences, and in this climate it was felt that short-term earthquake prediction, if not just around the corner, was at least conceivable, and that steady improvements in long-range earthquake forecasting would come with research.

The significance of this optimism from a policy standpoint is that it favors a mitigation strategy in which federal incentives for action are perceived as unnecessary. As we have seen, uncertainties in the timing, location, and severity of future earthquakes hinder both the acceptance and the execution of mitigation programs by nonfederal entities. Successful earthquake prediction, in removing this uncertainty, improves matters by providing a clear motivation for action and by delineating the intensity and geographic scope of the necessary mitigation, thereby constraining the cost.

In effect, a vastly refined foreknowledge of how, when, and where earthquakes occur can arguably be used to create both the desire and the expertise for the implementation of mitigation measures. In keeping with this philosophy, NEHRP was given neither regulatory teeth nor the authority to provide substantial incentives for mitigation. Instead, the program was intended to create a font of knowledge from which nonfederal

[20] U.S. Geological Survey, see footnote 15, pp. 27-28.

[21] Berke and Beatley, see footnote 15, p. 178.

[22] Andrew Coburn and Robin Spence, *Earthquake Protection* (Chichester, England: John Wiley & Sons, 1992), p. 315.

[23] Daniel J. Alesch and William J. Petak, *The Politics and Economics of Earthquake Hazard Mitigation* (CO: University of Colorado, Institute of Behavioral Science, 1986), p. 142; and Dennis S. Mileti et al., "Fostering Public Preparations for Natural Hazards: Lessons from the Parkfield Earthquake Prediction," *Environment*, vol. 34, No. 3, April 1992, p. 36.

authorities and the private sector would eagerly draw.

Although it is debatable whether NEHRP would have attained its societal goals even with widespread success in earthquake prediction (given the implementation difficulties discussed above), the fact is that prediction is not likely in the near future. This development is not the fault of the program. In fact, it is NEHRP-sponsored research that has begun to reveal just how complex, unpredictable, and variable earthquakes and their effects really are. Because of NEHRP we now know far more about earthquakes and far more about the structures and techniques that can withstand them. However, with this understanding comes a better appreciation of how deep and stubborn are the remaining uncertainties—uncertainties that work against the nonfederal adoption of mitigation measures.

HOW MATTERS MIGHT BE IMPROVED

The preceding sections have shown that implementation difficulties hinder both the adoption and the execution of seismic mitigation programs; these difficulties largely reflect the economic and political cost of mitigation as seen against a backdrop of uncertain seismic hazard and vulnerability. In the current NEHRP structure, federal activities to promote mitigation consist largely of outreach, media, and educational programs; such efforts may be expanded, or they may be supplemented by more aggressive implementation tactics (see chapter 1). Here, OTA suggests a range of directions that can improve mitigation efforts.

The implementation needs of California are largely different from those of the rest of the country. Within California, continual seismic activity in a heavily urbanized state has led to significant public and governmental awareness of earthquake risks and hazards. This awareness has resulted in California leading the country in mitigation and preparedness efforts. Because California already has in place a basic mitigation framework of new building codes, selective policies of land-use planning, and active public outreach programs through schools and the media, the main implementation issue is execution, rather than adoption. That is, although some adoption problems remain (notably, the retrofit of "pre-code" buildings that do not comply with the latest building standards), for the most part one can concentrate on expanding and optimizing the mitigation efforts that are already in play.

In contrast, regions outside California display a broad spectrum of mitigation activity, ranging from encouraging progress in some communities of the Pacific Northwest, to low or nonexistent activity in many parts of the East Coast, central United States, and Intermountain West. For some of these areas, earthquake severity and timing are such that seismic concerns are reasonably seen as low priority (e.g., Boston). In others, potentially high risks are masked by relatively short histories of urban settlement and a relative absence of frequent, moderate-level seismic activity (e.g., the Intermountain West). In concert with the extreme levels of scientific uncertainty that seem to surround non-California earthquakes, these factors have greatly inhibited the adoption of many mitigation measures.

Thus, in basic terms, one would hope to improve program *execution* in California while encouraging program *adoption* elsewhere. Efforts to achieve these aims can be made in each of the three NEHRP components: earth science, engineering, and implementation.

Earth Science Research Measures

Earth Science: Reducing Loss of Life

Earth science research efforts that can improve life safety in future earthquakes fall into two broad categories: basic research that will reduce the likelihood of "surprises" in the future size, location, and timing of severely damaging earthquakes (and in so doing, increase the likelihood that mitigation measures are adopted); and more directed, microzonation-style studies to identify localized troublespots. Both categories are of use throughout the country, although their roles vary subtly according to geography.

In areas where implementation is currently weak (i.e., much of the country outside of California), reductions in loss of life (and economic losses) require that seismic building codes and other mitigation measures be adopted by at-risk communities. **Because great uncertainties over earthquake location, severity, and timing act as a disincentive to action, the earth science priority here is for basic research that can better zero in on when, where, and how strongly an earthquake will strike.** This research must not only delineate where earthquakes are likely to occur (information that increases the perceived benefit of mitigation), but also identify areas of relative safety (which reduces the geographic extent—and thus cost—of mitigation).

Where there exists some degree of interest in seismic mitigation, the potential importance of microzonation-style research grows. In localities where the earthquake danger is recognized, such research allows communities to sidestep opposition to broad-based mitigation by narrowly targeting exceptionally hazardous sites (this is the approach taken by Utah's Salt Lake County Natural Hazards Ordinance, discussed in box 4-2). More mitigation-friendly locales will likely use such research to help prioritize efforts in seismic retrofit and demolition; to identify situations in which land-use planning is the most effective implementation option (i.e., places where no reasonable amount of engineering can overcome the effects of catastrophic liquefaction, landslides, or tsunamis); and to optimize building code provisions for the characteristics of future ground motions.[24]

Earth Science: Reducing Economic Losses

Although the importance of earth science research for life safety is clear, its role in minimizing economic loss is somewhat less so. This uncertainly stems from our lack of understanding of the true sources of earthquake economic loss.

On the one hand, successful earth science research can reduce future economic losses in those regions where mitigation activity is relatively weak. Where mitigation measures are hampered by uncertainty over risk and hazard, refined earthquake forecasts can encourage their adoption. In addition, microzonation research can allow otherwise reluctant communities to direct their efforts to geographically limited locales, thus fostering adoption where there would otherwise be none. In both cases, research can lead to loss reduction through the encouragement of basic mitigation activity.

In regions where mitigation measures are already in place, however, continued earth science research plays a more uncertain role. Because such regions typically experience high seismic activity (e.g., southern California), sheer prudence dictates that basic seismic research and ground-motion studies be continued so as to reduce the likelihood of major surprises in earthquake location and severity (surprises that can leave even a diligent community unprepared for a future calamity). However, in the absence of such surprises, there is the possibility that continued research will beget diminishing returns. At issue is the true source of earthquake economic losses: if the bulk of such losses stem from episodes of major damage, then refined earthquake and microzonation forecasts can reduce losses by permitting better targeting of vulnerable structures (particularly if the research is directed toward lifeline survivability). However, if the majority of earthquake losses stem ultimately from moderate-to-minor ground-shaking damage distributed over a wide area, then efforts to pinpoint local trouble spots (as well as to refine estimates of earthquake timing and location) will not address the major source of economic loss. **Uncertainty over the true origins of earthquake-induced economic**

[24] Damage in the 1994 Northridge quake indicates that even moderate earthquakes can subject buildings to stresses far greater than have been expected, and one must assume that larger quakes possess a similar potential. Credible ground-motion estimates, derived from microzonation-style modeling and from data collected in actual events, are therefore essential to writing effective building codes. However, such estimates will be of use only if actively transmitted to the engineering community in a manner that recognizes the need for codes to be stable over time.

losses therefore impede discussions of earthquake loss reduction, and remain an important avenue for social science research.

Engineering Research Measures

Engineering Measures: Reducing Loss of Life

From an implementation perspective, improved life safety can arise from engineering research if retrofit costs are brought down, and if better tools are devised to assess building vulnerability.

Particularly in California, where new construction is reasonably well handled by codes,[25] measures to save lives will center on older structures, particularly buildings of unreinforced masonry. Although many factors inhibit the systematic retrofitting of URMs and other noncomplying structures, a major obstacle to retrofit action is simply cost. Successful research into more cost-effective retrofit techniques—particularly if the techniques can be shown to reduce post-earthquake repair bills dramatically—can therefore make retrofit programs more palatable both to local policymakers and to building owners.

Opposition to retrofit programs can be further reduced if it can reliably be determined what buildings do *not* need to be retrofitted. For example, not all URM structures display the same vulnerability to earthquake damage, and a means of distinguishing the most vulnerable from the least can permit a more selective targeting of structures. Ongoing efforts to develop an analytic means of making such distinctions can therefore enhance program effectiveness while reducing the number of affected building owners and occupants.

Engineering Measures: Reducing Economic Losses

As noted above, current building codes focus on structural issues while giving little attention to nonstructural and contents damage. Because the latter kind of damage can generate most of the economic losses that accompany damaging earthquakes, research into effective, low-cost methods of reducing such damage might yield substantial rewards.

It is unclear, however, how to best incorporate nonstructural and contents damage concerns into current building codes. One difficulty is that such damage is often hard to proscribe in the language of a prescriptive code (e.g., a code cannot easily specify what steps a computer software company must take to safeguard its data and records, nor can it order individuals how to arrange furniture, bookshelves, or cooking equipment). Because of this limitation, one approach could be to replace prescriptive building codes with performance-based standards (i.e., codes that provide great flexibility of execution while requiring minimum standards of seismic performance). Such an approach has been adopted with some success in the construction of California hospitals, which are required to maintain functionality in the aftermath of a damaging earthquake (however, these codes are somewhat controversial in their need for painstaking execution). By defining design options appropriate to different levels of safety or performance, engineering research may increase the odds that performance-based codes attain a wider use.

A second approach to reducing economic losses would be to concentrate on the indirect effects of earthquake damage. In particular, because the federal government maintains some authority over lifeline systems (e.g., transportation and energy), a potentially significant avenue for economic loss reduction lies in the "hardening" (i.e., strengthening and introducing redundancy) of lifelines and vital response systems to reduce indirect losses and improve post-earthquake recovery. Such a move would be assisted by research into measures such as the preservation of potable and firefighting water systems, or the use of automatic shutoff devices on natural gas lines.

[25] Subject to the limitations noted in this chapter, including problems of enforcement and limited coverage of economic damage.

Direct Measures To Improve Implementation

More direct efforts to improve implementation will primarily involve education and outreach, technical assistance to nonfederal governments and organizations, and social science research into the nature of implementation bottlenecks. These efforts can be applied to the current implementation framework, or as preparation for a more vigorous federal mitigation role.

Actions that may assist implementation within the current framework include the following:

- Because individual local advocates and concerned professional organizations can play a powerful role in fostering and maintaining community interest in mitigation, efforts to create or assist advocates are of great potential impact. The federal government can assist advocates in this area by: ensuring that advocates have access to the latest information and educational materials on earthquake risks, supporting community activities as funding permits, or supplying direct technical and educational assistance to local or state governments.
- The more publicity there is concerning earthquakes, the more likely it is for individuals to become advocates. Thus media and public outreach activities can have a powerful indirect effect, both in fostering the appearance of advocates and in creating a supportive environment in which they may act. Public interest in earthquakes generally depends on how recently a major quake has occurred, but preparing outreach materials to take advantage of disaster windows is a prudent measure. Such outreach is relatively inexpensive and potentially productive, although in places where destructive seismic activity is extremely infrequent (e.g., the U.S. east coast), it is unlikely to create a surge of local activity.
- Research into the political and social science of mitigation success and failure can assist implementation by identifying stumbling points (e.g., factors hindering code enforcement) in the implementation process. Such research will not likely be undertaken without federal support.
- Perhaps the most promising implementation activity is to assist communities in their efforts at understanding risk, vulnerability, costs, benefits, and mitigation options. Workshops, conferences, and forums have been and will continue to be useful in disseminating such information, but strong efforts should be made to assign hard numbers to the predictions. In particular, communities must be given analytic tools for estimating likely losses in the event of a future earthquake, and credible means must be developed to predict the likely benefits of mitigation. At present, it is difficult to quantify these basic parameters, and it is this absence that perhaps most inhibits vigorous action at all mitigation levels.[26]
- In addition to supplying such informational assistance to at-risk communities, the federal government might wish to offer more direct technical aid. This aid can take the form of supplied expertise (e.g., mitigation efforts in the Salt Lake County of Utah were greatly enhanced by a three-year federal grant for hiring an in-house county geologist—see box 4-2), or through programs to assist in the education and training of engineers and design professionals in the principles of seismically resistant construction.
- To complement activities on the seismic front, efforts can be made to incorporate seismic implementation into a larger "all-hazards" framework. Much of the nonstructural preparation 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 eco-

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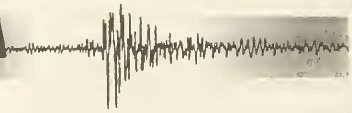
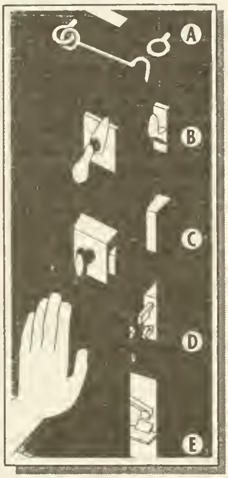
[26] The Federal Emergency Management Agency is currently supporting development of a computer-based tool to assist communities in loss estimation, a promising endeavor that may considerably aid future implementation efforts.

What To Do Right Now To Prepare:



HUMBOLDT EARTHQUAKE EDUCATION CENTER



LATCHES

For many residents of the North Coast, a large financial loss will come if the doors of kitchen cabinets are shaken open, throwing contents to the floor. A few dollars spent now can prevent most of that loss.

In choosing a latch, consider looks and ease of use. The standard hook and eye (A) is an inexpensive and secure latch, but you may not close it every time you enter the cabinet because it takes extra effort to do so. A child-proof catch (E) prevents a door from opening more than an inch or two. These catches close automatically, but they require an extra action every time you open the door.

Some standard types of secure latches mount on the surface of the door (B, C). Latches are available that mount inside the door (D), hold the door firmly shut, and open by being pushed gently inward. These are marketed under names such as push latch, touch latch, or pressure catch. If you cannot find these latches, ask your hardware dealer to order them for you.

Protect Your Belongings

Falling objects and toppling furniture can be dangerous and expensive to replace or repair.

- Move heavy items, such as pictures, mirrors or tall dressers, away from your bed.
- Secure tall furniture and bookcases with lag bolts to wall studs. Add lips to shelves to prevent costly items from sliding off. Be sure adjustable shelves cannot slide off their supports.
- Put latches on cabinet doors, especially at home in your kitchen and at work or school laboratories
- Fasten heavy or precious items to shelves or tables. Secure file cabinets, computers, televisions and machinery that may overturn during an earthquake.
- Store potentially hazardous materials such as cleaners, fertilizers, chemicals, and petroleum products in appropriate containers and in sturdy cabinets fastened to the wall or floor
- In your office, be sure heavy objects are fastened to the building structure and not just to a movable wall. Ask a carpenter or an electrician to determine whether light fixtures and modular ceiling systems are securely fastened.
- Be sure your water heater is fastened to the wall studs and that all gas heaters and appliances are connected to the gas pipe through flexible tubing. If you use propane gas, be sure the storage tank is secured against overturning and sliding.
- Secure your wood stove to wall or floor studs. Make sure you have a fire extinguisher close at hand.
- Check with your school officials to be sure they have taken similar precautions.

6

Outreach and education materials, such as this pamphlet on safeguarding household effects, can both foster and guide mitigation efforts.

nomic attractiveness when viewed in a larger context.

- Lastly, consideration can be given to making NEHRP less of a purely voluntary, information-driven program by attaching strong incentives for action and regulatory or economic penalties to inaction (e.g., through changes in federal disaster relief or insurance). These options, which are discussed in chapter 1, can also act as a tool for enforcement (e.g., by using pre-mortgage inspections to ensure building code compliance).

All of the above efforts require insight into the many political, economic, social, and practical forces that shape the implementation process. It should be reemphasized that the current understanding of these forces is by no means complete. Social science research into the behavior of communities and individuals is thus of considerable importance—all the more so if substantial changes to current policy are being considered (e.g., the possible use of mandatory earthquake insurance to foster seismic mitigation). Ongoing NEHRP-funded social science research has already illuminated many of the factors affecting implementation within the current NEHRP framework; this effort might profitably be strengthened or extended. In particular, substantial social science knowledge gaps remain that hinder efforts to improve NEHRP. Chief among these are the following:

- How might individuals respond to financial incentives (such as insurance) for implementation?
- Does the current de facto insurance framework (federal disaster assistance) inhibit state, local, and private implementation efforts, and if so, to what extent?
- Where do the true bottlenecks occur in the enforcement process for seismic building codes (e.g., to what extent does the trouble lie in on-site building inspection, in plan checking at the design stage, or in unexpected variability in construction practices and standards)?
- Will different parts of the country respond differently to proposed implementation strategies, and if so, what regional variations are to be expected?

Successful research into these matters will greatly improve action within the current implementation framework, and will be critical to any efforts at extending program scope.

Appendix A: The National Earthquake Hazards Reduction Program A

The 1964 Alaska and 1971 San Fernando, California, earthquakes increased public awareness of U.S earthquake risks and led to numerous task forces, reports, and proposals for establishing a federal earthquake program. Then, in the mid-1970s, a number of events led to the growing momentum for federal legislation:

- China successfully predicted a major earthquake before it occurred, saving at least tens of thousands of lives.
- China and Guatemala suffered large and damaging earthquakes.
- The "Palmdale" bulge, a section of the San Andreas fault showing uplift, was identified.
- Various expert panels and committees released reports on earthquakes, some of which stated or implied that the United States was behind China, Japan, and Russia in its commitment to and understanding of earthquake prediction.
- There was considerable optimism in the scientific community that earthquake prediction was feasible. For example, a National Academy of Sciences report recommended that the United States make a national commitment to a long-term earthquake prediction program.[1]
- The President's Commission on Science and Technology put together a panel that produced a report (commonly known as the Newmark-Stever report) laying out a preliminary plan and budget for a federal earthquake program.

EARTHQUAKE HAZARDS REDUCTION ACT

Various bills to establish a federal earthquake program were introduced in Congress in the early and mid-1970s. However, none were enacted until 1977, when the Earthquake Hazards Reduction Act[2] was passed. Several aspects of the original legislation are worthy of note. First, it was developed and enacted in an era of great optimism about the potential for earthquake prediction—that is, accurate short-term forecasts of the location, magnitude, and timing of earthquakes. The legislation reflects this, for example, stating:

[1] National Research Council, *Predicting Earthquakes: A Scientific and Technical Evaluation—with Implications for Society* (Washington, DC: National Academy of Sciences, 1976), p. 3.

[2] Public Law 95-124, Oct. 7, 1977.

> A well-funded seismological research program in earthquake prediction could provide data adequate for the design of an operational system that could predict accurately the time, place, magnitude, and physical effects of earthquakes.[3]

Second, although the bill listed a number of nonresearch objectives, including public education and code development, much of the original legislation was directed toward research. For example, the bill authorized agency appropriations only for the U.S. Geological Survey (USGS) and the National Science Foundation (NSF), to conduct or fund earthquake-related research. Third, the legislation did not make clear how the nonresearch objectives were to be implemented. Instead, responsibility for implementation was given to the President, who was charged with developing an implementation plan. Thus, the program began with immediate activity by two relatively strong research organizations, USGS and NSF, but without a clearly defined implementation component and without a lead agency.

The President's implementation plan,[4] sent to Congress in 1978, gave much of the responsibility for implementation to a "lead agency," although just *which* agency was not specified. Other federal agencies were given specific tasks, including participation in a multiagency task force that was to develop design standards for federal projects. Executive Order 12148, dated July 20, 1979, designated the then newly created Federal Emergency Management Agency (FEMA) as the lead agency.[5]

REAUTHORIZATION HISTORY

The National Earthquake Hazards Reduction Program (NEHRP) has been reauthorized eight times since its inception (see table A-1); however, only two of these reauthorizations made significant changes to the program. The 1980 reauthorization[6] established FEMA as the lead agency, and extended NEHRP authorizations to FEMA and to the National Bureau of Standards (now the National Institute of Standards and Technology, NIST).

The 1990 reauthorization (Public Law 101-614) made several substantial changes. The Senate report accompanying the final bill noted several congressional concerns with NEHRP, including,

> . . . the slow and, in the view of many experts, inadequate application of research findings to earthquake preparedness; . . . the need to improve coordination of the agencies in the program and define better their roles; . . . the need to update and broaden the scope of the [NEHRP].[7]

In response to these and other concerns, the following major changes were made:

- references to earthquake prediction and control were downplayed;
- program objectives were clarified and expanded, for example, education, lifeline research, earthquake insurance, and land-use policy;
- the role of FEMA as lead agency was clarified and defined, for example, program budgets, written program plans, reports to Congress, a

[3] Ibid., sec. 2(4).

[4] Executive Office of the President, "The National Earthquake Hazards Reduction Program," June 22, 1978.

[5] U.S. Congress, General Accounting Office, "Stronger Direction Needed for the National Earthquake Program," GAO/RCED-83-103, July 26, 1983, p. 2.

[6] Public Law 96-472, Oct. 19, 1980.

[7] U.S. Congress, Senate Committee on Commerce, Science, and Transportation, *NEHRP Reauthorization Act*, Report 101-446 (Washington, DC: Aug. 30, 1990), p. 3.

TABLE A-1: Reauthorization History

Public Law number	Date of passage	Provided reauthorization for fiscal years	Significant changes or additions
95-124	Oct. 7, 1977	1978, 1979, 1980	Defined and initiated program.
			Authorized funds for U.S. Geological Survey and National Science Foundation only.
			Directed President to select lead agency for implementation.
96-472	Oct. 19, 1980	1981	Delined Federal Emergency Management Agency (FEMA) as lead agency.
			Authorized lunds lor FEMA and National Bureau ol Standards (now National Institute of Standards and Technology).
97-80	Nov. 20, 1981	1982	None.
97-464	Jan. 12, 1983	1983	None.
98-241	Feb. 22, 1984	1984, 1985	None.
99-105	Sept. 30, 1985	1986, 1987	None.
100-252	Feb. 29, 1988	1988, 1989, 1990	None.
101-614	Nov 16, 1990	1991, 1992, 1993	Eliminated some relerences to prediction consequences and to earthquake control.
			Clarilied objectives of National Earthquake Hazards Reduction Program, emphasizing implementation.
			Required seismic regulations for new federal buildings, and the adoption of seismic regulations for existing lederal buildings.
			Clarified agency roles.
103-374	Oct. 20, 1994	1994, 1995, 1996	None.

SOURCE. Office of Technology Assessment, 1995

comprehensive education program, and grants to states;

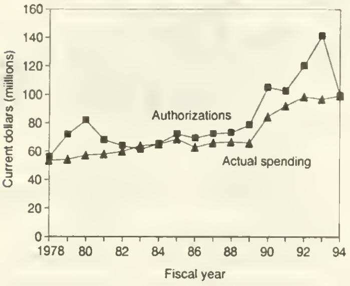
- the roles of USGS, NSF, and NIST were clarified (but not altered significantly); and
- the President was required to ensure that federal agencies issue seismic safety regulations for new buildings, and adopt seismic standards for existing federal buildings lacking adequate seismic resistance.

The 1994 reauthorization made no substantive changes in NEHRP, however the hearings and language in the report accompanying HR 3485 out of the House Committee on Science, Space, and Technology (now the Committee on Science) provide some insight into congressional views of and concerns with NEHRP. The report stated:

> The [House Science, Space, and Technology] Committee is concerned about the effectiveness of the NEHRP. Recent hearings have raised long-standing concerns about NEHRP—lack of an overall strategic plan; insufficient coordination among the agencies to shape a unified, coherent program; insufficient application of results of NEHRP research to limit losses; and inadequate emphasis on research to mitigate earthquake damage.[8]

[8] U.S. Congress, House Committee on Science, Space, and Technology, "Earthquake Hazards Reduction Act Reauthorization," Report 103-360, Nov. 15, 1993, p. 6.

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



SOURCE Office of Technology Assessment, 1995

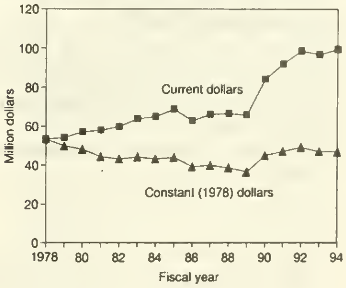
The Committee took two steps to address these concerns: first, members of the House of Representatives sent a letter to the President requesting an executive branch review of NEHRP. The executive branch review was given to the White House Office of Science and Technology Policy, which as of August 1995 had not yet issued their findings. Second, the Committee sent a letter to the director of the congressional Office of Technology Assessment (OTA) requesting that OTA "review Federal efforts to reduce earthquake damage." This report is OTA's response to that request.

BUDGET

As for all federal programs, the budget process for NEHRP involves two separate congressional processes, authorizations, and appropriations. NEHRP's authorizations give permission to the agencies to spend up to the amount authorized for the activities discussed in the legislation. The appropriations process, however, provides the actual funding to do the work. For NEHRP, as for almost all government programs, authorizations and appropriations are under separate committees of Congress. As NEHRP is a relatively small component of the agency budget, the congressional appropriations committees generally do not directly specify the amount of money to be spent on NEHRP activities. Instead, each agency determines its own budget priorities in conjunction with the Office of Management and Budget, and submits this budget (which specifies NEHRP spending levels) in the President's annual budget request. The appropriations committee, in turn, either accepts this overall budget level or sets it at a different level.

In the past, NEHRP authorizations have usually exceeded the actual spending (see figure A-1). Actual spending has increased in current dollars, but has decreased overall in constant dollars (see figure A-2).

FIGURE A-2: NEHRP Spending, FY 1978-94 (in current and constant dollars)



SOURCE: Office of Technology Assessment, 1995

Appendix B: Agency Efforts in the Current NEHRP

B

Four agencies—the National Science Foundation (NSF), the U.S. Geological Survey (USGS), the Federal Emergency Management Agency (FEMA), and the National Institute of Standards and Technology (NIST)—have specific responsibilities within the National Earthquake Hazards Reduction Program (NEHRP). Figure B-1 shows the division of NEHRP funding among the principal agencies. This appendix describes each agency's current NEHRP efforts and outlines earthquake-related activities by other federal agencies that are outside the formal NEHRP framework.

U.S. GEOLOGICAL SURVEY

USGS receives the largest share of NEHRP funds—about $50 million in FY 1994, accounting for more than half of all NEHRP spending. In recent years, USGS has used its NEHRP funds to pursue four goals:

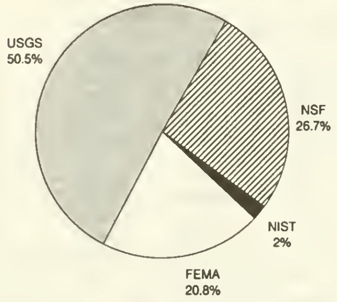
- understanding what happens at the earthquake source,
- determining the potential for future earthquakes,
- predicting the effects of earthquakes, and
- developing applications for research results.[1]

Supporting efforts span a wide range of activities, from research into basic earthquake processes to mapping expected ground motions for use in building design codes. More than two-thirds of NEHRP funding is used internally—to support USGS scientists in regional programs, laboratory and field activities, national hazards assessment projects, and seismic network operation. The remainder is spent as grants to outside researchers for specific projects. In general, the internal work focuses on applying knowledge to describe hazards, while the external program emphasizes expanding and strengthening the base of scientific knowledge.

Three specific aspects of U.S. Geological Survey's NEHRP-related work are discussed below: the geographic focus of the work, efforts made at

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

FIGURE B-1: NEHRP Spending by Agency, FY 1994



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

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

improving technology transfer, and the post-earthquake investigation program.

Geographic Focus

Concentrated for years primarily in California, USGS research and hazard assessment activities expanded in the mid-1980s to include a multiyear effort to fully characterize seismic hazards along the Wasatch fault zone in Utah. Beginning in 1991, USGS divided a substantial portion of its resources among four regions where the earthquake hazard is most severe: southern California, northern California, the Pacific Northwest, and the central United States[2] (see table B-1). A regional coordinator is responsible for coordinating all aspects of the program with state and local agencies, engineering groups, county emergency managers, and planners.[3] Although California still receives the bulk of the funding set aside for regional studies, USGS has shifted toward a more national program. The most noticeable remaining gap in coverage is metropolitan areas in the Northeast that have significant seismic risk (e.g., Boston and New York City).

Technology Transfer

USGS has several programs intended to promote the use of agency-produced knowledge and tools. Examples include the following:

- USGS works with the California Division of Mines and Geology (a state agency) to develop geographical information systems for use in studying high seismic risk regions of the state.
- USGS supports the Southern California Earthquake Center (SCEC). SCEC is a multidisciplinary effort to catalog and quantify regional earthquake hazards and to transfer this information to the mitigation community. It is described further under NSF activities.
- With FEMA, USGS has assisted in establishing the Coordinating Organization for Northern California Earthquake Research and Technology (CONCERT). With members from government agencies and private sector organizations, CONCERT provides a framework for members to exchange ideas and hold public workshops. Their objective is more effective transfer of new technologies and research results to the region's engineering community.
- USGS encourages the exchange of ideas and expertise between "sister cities" with similar seismic risks. One of the first such exchanges

[2] The Pacific Northwest refers to northernmost California, Oregon, Washington, and Alaska; the central United States include Indiana, Illinois, Missouri, Kentucky, Tennessee, Arkansas, and Mississippi. Craig Weaver, Acting USGS NEHRP Coordinator, personal communication, May 9, 1995.

[3] Along with three discipline coordinators (who oversee geographically based studies outside the four primary regions, laboratory and theoretical studies, and the national seismic network system), the four regional coordinators oversee peer review panels that advise USGS on funding priorities. Ibid.

TABLE B-1: USGS Spending Under NEHRP, FY 1995

Program element	FY 1995 spending (million dollars)		
	Internal	External	Total
Northern California	7,096.7	1,830.0	8,926.7
Southern California	5,385.2	1,900.0	7,285.2
Pacific Northwest	2,434.2	1,316.1	3,750.3
Central United States	1,853.6	1,000.5	2,854.1
National and international	2,772.1	1,067.2	3,839.3
Seismic networks	5,040.0	2,620.0	7,660.0
Earthquake process and theory	2,491.3	919.8	3,411.1
Southern California Earthquake Center	—	1,200.0	1,200.0
Other	7,870.0	2,118.4	9,988.4
Total	**34,943.1**	**13,972.0**	**48,915.1**

NOTE: Other includes miscellaneous administration and program assessments

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

involved hazard planners and engineers from Watsonville, California, and their counterparts in Anchorage, Alaska. Other sister-city meetings are planned.

- USGS operates the National Earthquake Information Center (NEIC) in Golden, Colorado. NEIC has three main missions: 1) to determine, as accurately and rapidly as possible, the location and magnitude of damaging earthquakes; 2) to collect and distribute seismic data for use in research; and 3) to pursue research into locating and understanding earthquakes. In support of these missions, NEIC distributes a number of products (see table B-2).
- USGS makes earth science data and maps available over the Internet. For example, data centers in northern and southern California provide maps of recent regional earthquakes, the location of and data from geodetic and seismic monitoring stations, and links to other Internet sites with related data or topics. Other information is becoming increasingly available for use by researchers, educators, and the public.

Future Directions

NEHRP achievements in recent years include increased awareness on the part of state and local officials, engineering associations, and other private sector organizations of earthquake hazards and risks. According to USGS, these groups have become more sophisticated as to what they need next from NEHRP. To better serve their needs, USGS has redesigned the major elements of its FY 1996 NEHRP effort as follows:

- assessing national and regional earthquake hazard and risk,
- assessing major urban area earthquake hazard and risk,
- understanding earthquake processes,
- providing national real-time earthquake hazard and risk assessment, and
- providing national geologic hazards information services.[4]

[4] Ibid.

TABLE B-2: National Earthquake Information Center Products

Title	Description
Quick Epicenter Determinations	Very preliminary list of significant quakes, compiled daily and available for computer access by telephone line.
Preliminary Determination of Epicenters	Initial locations prepared and distributed weekly to those contributing data to the NEIC; also published in a monthly listing available via the Superintendent of Documents in Washington, DC.
Earthquake Data Report	Monthly publication that provides additional, more detailed information for seismologists on a data exchange basis.
Other products	CD-ROMs, maps, and an annual book of U.S. earthquakes.

SOURCE: U.S. Geological Survey, National Earthquake Information Center, *1994 Guide to Products and Services* (Golden, CO 1994)

Post-Earthquake Investigations

The 1990 NEHRP reauthorization[5] directed USGS to establish a post-earthquake investigation program, to study and learn lessons from major earthquakes. USGS has supported post-quake work for both U.S. and non-U.S., major earthquakes. This work has allowed USGS to collect perishable data on aftershocks and earthquake-induced damage.

After the Northridge earthquake in 1994, Congress passed a supplemental appropriations bill that, in part, funded USGS to install a seismic monitoring system that can better measure strong ground motions. This system will improve the ability to provide real-time information on earthquake size, location, and likely effects.

NATIONAL SCIENCE FOUNDATION

NSF receives about one-quarter of the NEHRP funding. Its NEHRP spending is in two distinct areas: fundamental earth science, and engineering and social science research. The earth science research, overseen by the Earth Sciences Division in the Directorate for Geosciences, accounts for 11.4 percent of NEHRP funds in FY 1994. The engineering and social science research in the Earthquake Hazard Mitigation Program within the Directorate for Engineering accounts for 15.6 percent of NEHRP funds. Figure B-2 provides funding trends in current dollars for both areas.

Earth Science Research

NSF uses NEHRP resources to support earthquake-related earth science research through two main channels: direct grants to researchers and support for various university consortia, including the Incorporated Research Institutions for Seismology (IRIS) and the Southern California Earthquake Center (see table B-3). In addition, using non-NEHRP funds, NSF supports the University Navstar Consortium (UNAVCO) that provides technical assistance and equipment to investigators for geodetic studies and other earth science research.

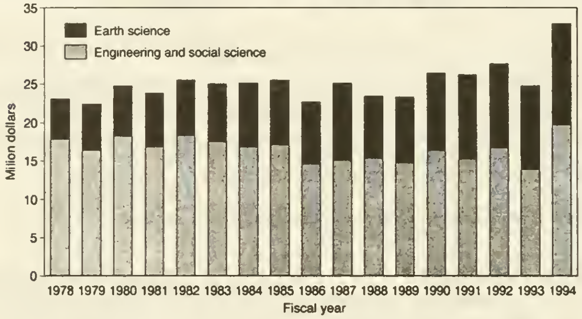
Direct Grants

NSF awards research grants directly to investigators for the study of earthquake sources, active tectonics, earthquake dating and paleoseismology, and shallow crustal seismicity.[6] For FY 1990 to 1994, instrument-based seismology, geodesy, and other tectonics received the bulk of the awards (on

[5] Public Law 101-614, Nov. 16, 1990.

[6] James Whitcomb, Director, Geophysics Program, National Science Foundation, personal communication, Nov. 21, 1994.

FIGURE B-2: NSF Spending Under NEHRP, FY 1978-94



SOURCE: Office of Technology Assessment, 1995, based on National Science Foundation budget data.

the order of 90 percent); paleoseismology and microzonation efforts, in contrast, comprised about 5 percent of the overall budget for direct grants (see table B-4).

Incorporated Research Institutions for Seismology

IRIS is a university-based consortium that supports research in seismology by providing facilities for instrumentation and for data collection, archiving, and distribution. IRIS is supported by NSF (in part with NEHRP funds) and by the Air Force Office of Scientific Research.

IRIS, in partnership with USGS, is building a multiuse global network of modern, digital seismograph stations. According to IRIS, the Global Seismographic Network supports NEHRP by enabling detailed assessments of the frequency of earthquakes around the world and of their anticipated ground motions. In 1994, 20 new stations were added to the network, bringing the total to 72.[7]

Through PASSCAL (Program for Array Seismic Studies of the Continental Lithosphere), IRIS provides portable instrumentation and support facilities for the study of seismic sources and earth structure. Under development is the Rapid Array Mobilization Program, intended to support rapid deployment of instruments in the field immediately after a large earthquake or volcanic event.[8]

Another significant function of IRIS is the Data Management System, which tracks the operation of the stations and archives the data. In addition, the IRIS Data Management Center (in Seattle, Washington) makes available via the Internet these data, customized data products, and a number of other historical data sets.

[7] Incorporated Research Institutions for Seismology, *1994 Annual Report* (Arlington, VA: 1994), p. 5.

[8] Incorporated Research Institutions for Seismology, *1992 Annual Report* (Arlington, VA: 1992), p. 18.

TABLE B-3: NSF Earth Science Spending, FY 1994

Element	Spending (million dollars)
Direct grants	$4.3
Incorporated Research Institutions for Seismology	3.6
Southern California Earthquake Center	3.3
Total	$11.2

SOURCE. Office of Technology Assessment, 1995, based on detailed National Science Foundation budget date

TABLE B-4: Allocation of NSF Investigator Awards in Earth Science, FY 1990-94

Research area	Award totals (thousand dollars)	Percentage of overall awards
Seismology	$10,450	48.3
Tectonics		
Geodesy	3,763	17.4
Nongeodetic	4,966	22.9
Paleoseismology	711	3.3
Microzonation	383	1.8
Tsunami	305	1.4
Other	1,077	5.0
Total NSF grants	$21,655	100.0

NOTES: Other includes support for workshops, travel, and conferences. The total does not include staff salary and expenses.

SOURCE: Office of Technology Assessment, based on 1994 National Science Foundation geosciences award data

Southern California Earthquake Center

SCEC serves as the focal point for regional studies of earthquake hazards and risk mitigation measures. The principal institutions involved are: University of Southern California; University of California—Los Angeles, San Diego, and Santa Barbara; California Institute of Technology; and Columbia University.

The center has a multidisciplinary outlook that promotes earthquake hazard reduction by defining when and where damaging earthquakes will occur in southern California, calculating expected ground motions, and communicating this information to the practicing engineering community and the public. Products include conditional probabilities for major faults, maps of seismotectonic source zones and regional probabilistic seismic hazards, assessments of the implications of recent patterns of seismicity in the greater Los Angeles area, and up-to-date earthquake source databases.

SCEC also supports the operation of a seismic network and several data centers. In addition, the center has facilitated installation of a comprehensive crustal strain monitoring network using the Global Positioning System (GPS). This is intended to provide improved hazard estimation from regional strain rates and increased understanding of post-quake deformation patterns.

TABLE B-5: NSF Earthquake Engineering Budget (excluding NCEER), FY 1994

Area	Budget (thousand dollars)	Research examples
Geotechnical	$2,621	Liquefaction, tsunamis.
Structural	2,722	Active controls, repair and rehabilitation.
Architectural and mechanical systems	2,719	Active controls, hazard evaluation.
Earthquake systems integration	2,567	Planning, social science.
Total	$10,629	

NOTE: Including the $4 million awarded to the National Earthquake Engineering Research Center (NCEER), the total FY 1994 National Science Foundation engineering budget was $14 629 million.

SOURCE: Office of Technology Assessment, 1995, based on National Science Foundation detailed budget data

Principal support comes from NSF (SCEC is an NSF Science and Technology Center) and USGS; SCEC is also supported by FEMA, the California Department of Transportation, and the City and County of Los Angeles.

University Navstar Consortium

UNAVCO maintains a standardized GPS equipment pool and data archiving center. One of the primary applications of geodetic measurements to earthquake research is the comparison of contemporary plate velocities and the rates of intraplate and plate boundary zone deformation with geological and geophysical observations and models.[9] Space-based techniques have revolutionized geodetic studies; they offer significant improvements over surface techniques in several applications.

Earthquake Engineering

The NSF earthquake engineering budget for FY 1994 was $14.6 million. It includes $4 million for the National Center for Earthquake Engineering Research (NCEER); the remainder is divided among four major research areas (see table B-5).

National Center for Earthquake Engineering Research

NCEER, located in Buffalo, New York, was established in 1986 with a five-year, $25-million grant from NSF.[10] This grant was renewed in May 1991 for five more years and $21 million. Additional funds for the center are provided by the State of New York and by various institutions.[11] The center's mission is to "advance engineering, planning and preparedness to minimize the damaging effects that earthquakes have."[12] As summarized in

[9] University Navstar Consortium, *FY95-99 Proposal* (Boulder, CO: n.d.), p. 7. Besides earthquake-related research, UNAVCO staff collaborate with the National Aeronatics and Space Administration, the National Center for Atmospheric Research, the National Oceanic and Atmospheric Administration, the Federal Aviation Administration, and university investigators in projects related to solid earth dynamics, climate, and meteorology.

[10] The decision to award this grant to the State University of New York at Buffalo, instead of to a competing bid from California researchers, was a controversial one. The story of this battle is told in VSP Associates, Inc., "To Save Lives and Protect Property," final report prepared for the Federal Emergency Management Agency, Nov. 1, 1988, appendix C.

[11] For example, the total NCEER budget in 1993-94 was $11.5 million: $4.0 million from NSF, $3.0 million from the Federal Highway Administration for research into the seismic vulnerability of the national highway system, $2.0 million from the state of New York, and $2.5 million from other sources. National Center for Earthquake Engineering Research, *Program Overview 1992-94* (Buffalo, NY: 1994), p. 30.

[12] Ibid., p. 1.

TABLE B-6: Research Funded by NCEER, 1993-94

Area	Funding (thousand dollars)	Examples
Seismic hazard and ground motion	$384	Ground motion and site response, seismic zonation.
Geotechnical engineering	375	Liquefaction and lifelines
Structures and systems	1,025	Retrofit methods, lifeline system analysis.
Risk and reliability	344	Development of risk-based design criteria.
Intelligent and protective systems	826	Base isolation, hybrid control systems
Socioeconomic Issues	600	Insurance and mitigation relationships, estimating damage with geographical information systems, hazard perception.
Implementation activities	446	Workshops, education and training.

SOURCE: Office of Technology Assessment, 1995, based on unpublished National Center for Earthquake Engineering Research (NCEER) budget data.

table B-6, the research portfolio supported by NCEER ranges from geotechnical engineering to socioeconomic issues.[13]

Geotechnical

NSF-sponsored work on geotechnical engineering includes studies of liquefaction, tsunamis, the response of soils to earthquakes, and the response of structures to ground motion. This research is, for the most part, applicable to all structures, including new and existing buildings and lifelines.

Structural

NSF-funded efforts in structures and earthquakes include support of research in active and hybrid control systems, design methodologies, seismic behavior of components such as reinforced concrete frames or precast panels, and lifeline design. A significant fraction of the research in this category is in the area of "structural control"—the use of active or hybrid intelligent control systems to reduce seismic damage in structures.

Architectural and Mechanical Systems

Much of the work in architectural and mechanical systems looks at specific building components such as composite walls and reinforced concrete frames. As in the structural category, active or hybrid controls are a significant topic, accounting for almost one-third of the funding in this category.[14]

Earthquake Systems Integration

Behavioral, social science, planning, and similar research is funded in earthquake systems integration. Issues addressed include code enforcement, decisions to demolish or repair a building, information transfer, and international comparisons of mitigation.

[13] For futher information, see National Center for Earthquake Engineering Research, *Research Accomplishments 1986-1994* (Buffalo, NY: September 1994).

[14] Research into *structural control, active control, hybrid control*, or similar phrases accounts for 32 percent of funding in the architectural and mechanical areas. Source is NSF detailed budget data.

FEDERAL EMERGENCY MANAGEMENT AGENCY

FEMA has two distinct roles in NEHRP: 1) as lead agency, FEMA is charged with overall coordination of the program; and 2) it also has responsibility for implementation of earthquake mitigation measures.

History

FEMA's role in NEHRP can best be understood by looking at how its role has evolved over time. When NEHRP was founded in 1977, the legislation called for a lead agency but did not specify what agency was to take that role. FEMA was given lead agency status by executive order in 1979. This was confirmed by Congress in the NEHRP reauthorization for 1981,[15] which also provided an explicit authorization for FEMA spending on earthquakes.

In the early years of its NEHRP activities, FEMA functioned primarily as a coordinator rather than as a strong leader or director. A 1983 U.S. General Accounting Office (GAO) report criticized FEMA's leadership, noting that FEMA had not carried out several responsibilities assigned to it in the legislation. GAO found that "FEMA could better prepare the United States for a major earthquake by more aggressively implementing the [NEHRP] act's requirements and providing stronger guidance and direction to Federal agencies."[16] In 1987, an expert review committee, assembled to assist in NEHRP planning and review, noted that "serious questions were raised regarding FEMA's performance in its assigned role."[17] The committee recommended the creation of an oversight commission, with some budget authority for NEHRP activities.

The 1990 NEHRP reauthorization contained extensive reference to FEMA's role in NEHRP. Although there was not a clear change in FEMA's role, the legislation specifically directed FEMA to:

- prepare an annual NEHRP budget for review by the Office of Management and Budget,
- prepare a written NEHRP plan for Congress every three years,
- operate a program of state grants and technical assistance, and
- ensure appropriate implementation of mitigation measures.

According to the Senate report accompanying the legislation, the intent of this language was in part to separate FEMA's leadership function from its operational (implementation) role.[18]

The 1993-94 reauthorization hearings suggest that concerns over coordination and implementation continue. In the Senate hearings, a senator asked of the witnesses, "Has coordination among the four NEHRP agencies improved?"[19] In the House hearings, a representative asked, "Is the program doing enough to ensure application of its findings?"[20]

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[15] Public Law 96-472, Oct. 19, 1980.

[16] U.S. General Accounting Office, "Stronger Direction Needed for the National Earthquake Program," GAO/RCED-83-103, July 26, 1983, pp. i,ii.

[17] Federal Emergency Management Agency, "Commentary and Recommendations of the Expert Review Committee 1987," p. xiii.

[18] U.S. Congress, Senate Committee on Commerce, Science, and Transportation, *National Earthquake Hazards Reduction Program Reauthorization Act*, Report 101-446 (Washington, DC: Aug. 30, 1990), p. 12.

[19] U.S. Congress, Senate Committee on Commerce, Science, and Transportation, Subcommittee on Science, Space, and Technology, hearing, May 17, 1994, p. 4.

[20] U.S. Congresss, House Committee on Science, Space, and Technology, Subcommittee on Science, hearing, Sept. 14, 1993, p. 2.

TABLE B-7: FEMA Major Budget Components, FY 1993

Area	Approximate budget (million dollars)	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. Preparation of NEHRP Provisions.
State and local hazards reduction	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.
Multiple hazards	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," Nov 9, 1993

Current Activities

FEMA currently conducts a broad range of activities under its NEHRP mandate.[21] Table B-7 lists the FY 1993 budget and examples of activities for each of six core areas of effort.

Leadership

According to the 1994 NEHRP report to Congress,[22] recent activities under FEMA's leadership function include:

- preparation of NEHRP plans and reports to Congress,
- assessment of user needs,
- support of earthquake professional organizations,
- arranging interagency meetings,
- support of problem-focused studies—specific issues of concern to the earthquake community, and
- outreach programs for small businesses.

Design and Construction Standards

FEMA contributes to the development of practices and standards to reduce seismic risk in both new and existing structures. Examples include sponsoring the development of the *NEHRP Provi-*

[21] This section draws on Federal Emergency Management Agency, *Building for the Future*, NEHRP FY 1991-1992 Report to Congress (Washington, DC: December 1992); Federal Emergency Management Agency, *Preserving Resources through Earthquake Mitigation*, NEHRP FY 1993-1994 Report to Congress (Washington, DC: December 1994); and Federal Emergency Management Agency, Office of Earthquakes and Natural Hazards, "Funds Tracking Report, FY 1993," 1993.

[22] Federal Emergency Management Agency, *Preserving Resources through Earthquake Mitigation*, see footnote 21.

sions (a synthesis of design knowledge for adoption by model codes),[23] development of handbooks for retrofitting existing buildings, and support of an earthquake testing and research facility at the University of Nevada.

State and Local Hazards Reduction Program

States and local governments bear primary responsibility for implementing plans and technologies to increase the resilience of communities toward seismic hazards and thus minimize the long-term effects of earthquakes. Through its State and Local Hazards Reduction Program, FEMA provides grants to states, local governments, and multistate consortia to support their earthquake mitigation activities. Of the 43 states and territories[24] with low to very high degrees of seismic hazard, 28 participate in one manner or another in the FEMA program. Seventeen of these states joined NEHRP at its inception in 1977.

Activities funded by FEMA grants vary, but typically involve education, outreach, code adoption, training, and similar implementation activities. Indiana, for example, used FEMA funding to develop a brochure on techniques to measure risk in existing buildings, North Carolina used FEMA funding to update its building code to include seismic provisions, and Arizona conducted public awareness and education workshops.[25]

Financial Requirements

Current cost-sharing regulations are that FEMA provides 100 percent of the first year's funding; 25- and 35-percent in-kind matches are required for years two and three; and a 50-percent cash match from states is necessary for the following years.[26] The effects of the matching requirement vary greatly among states. Participation by some states appears to decline after reaching the 50-percent cash threshold; others have declined to participate at all because of the cash requirement.

For example, of the six states in the highest risk category, only Wyoming does not formally participate in NEHRP. Wyoming indicated that fourth-year financial requirements (i.e., 50-percent cash match) precluded such involvement. However, it does participate in NEHRP-related activities and belongs to the Western States Seismic Policy Council.

Program Elements

The five primary matching fund program elements are: Leadership and Program Management; Fundamental Research and Studies; Hazard Mapping, Risk Studies, and Loss Estimation; Hazard Mitigation; Preparedness and Response/Recovery Planning; and Information and Education. In addition, there is a "Special Projects and Other Programs" category. Under the latter, for example, New York State established in 1990 an Earthquake Lifelines Project to assess earthquake hazards, analyze lifeline vulnerability to support mitigation efforts, inform and educate the public, and provide training.

Typically, state efforts in the mitigation category relate to bridge safety analysis and reinforcement. New Jersey's activities under this program, however, also include a Prudent Business Practices program that encourages businesses to educate their employees and customers about seismic risks. At least nine states have activities in all NEHRP matching fund program areas.[27]

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[23] Building and Seismic Safety Council, *NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings*, 1991 Ed., prepared for Federal Emergency Management Agency (Washington, DC: January 1992).

[24] Including Guam, Puerto Rico, and the U.S. Virgin Islands.

[25] Examples from Federal Emergency Management Agency, *Building for the Future*, see footnote 21.

[26] VSP Associates, Inc., "State and Local Efforts To Reduce Earthquake Losses: Snapshots of Policies, Programs, and Funding," report prepared for the Office of Technology Assessment, Dec. 21, 1994.

[27] Arkansas, California, Kentucky, Mississippi, Missouri, Nevada, New Jersey, New Mexico, and Tennessee.

Regional Efforts

Three regional organizations play important roles in supporting individual states' seismic safety efforts: the Western States Seismic Policy Council, founded in 1977; the Central United States Earthquake Consortium (CUSEC), established in 1985; and, most recently, the Northeastern States Earthquake Consortium. CUSEC is the only one of the three groups that receives federal funds. These groups typically facilitate the exchange of information among states; provide a convenient mechanism for holding meetings and training sessions; act as an "issue network" by helping to forge state views on NEHRP priorities and programs; and, because of their administrative flexibility, can often do more things for their member states than individual state procedures allow.[28]

Education

FEMA supports a number of educational activities, including a course on post-earthquake reconstruction, a natural hazards information center, and dissemination of information on existing building retrofits.

With funding from USGS and NSF as well as FEMA, the Natural Hazards Research and Applications Information Center in Boulder, Colorado, serves as a national clearinghouse for information on the economic loss, human suffering, and social disruption caused by earthquakes, floods, hurricanes, tornadoes, and other natural disasters.

Multi-Hazard Assessment and Mitigation

Some FEMA activities in NEHRP address multiple hazards. For example, FEMA recently supported work on wind-resistant designs for buildings. Also under this heading is FEMA's support of the development of a loss estimation computer tool for use by cities and states in earthquake planning.

Federal Response Planning

FEMA has primary responsibility for preparing the federal government for national emergencies. FEMA activities include carrying out exercises, getting agencies to agree on emergency response plans, and supporting regional operating centers. FEMA has also supported urban search and rescue teams.

NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

NIST's role in NEHRP has been largely in applied engineering research and code development. The agency's funding under NEHRP has been low—less than $500,000 annually until the 1990s—so its NEHRP-related activities have been modest in size and scope. Current NEHRP funding is approximately $1.9 million.

Funding History

The initial NEHRP legislation did not provide explicit authorization for NIST (then the National Bureau of Standards), but NIST did receive some funding in the early years of NEHRP. The 1980 NEHRP reauthorization bill specifically authorized NIST as one of the four key NEHRP agencies, and these authorizations have continued in subsequent bills. In recent years, NIST's budget for earthquake-related activities has expanded due to contributions from other federal agencies, as well as a small contribution from the private sector. In FY 1994, for example, NIST received an additional $1.5 million from the Northridge supplemental appropriations for a total NIST earthquake-related budget of nearly $3.6 million.[29]

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[28] Examples include securing out-of-state consulting assistance and paying honoraria and invitational travel so that speakers can participate in training conferences.

[29] Richard N. Wright, Director, Building and Fire Research Laboratory, National Institute of Standards and Technology, testimony at hearings before the Senate Committee on Commerce, Science, and Transportation, May 17, 1994, table 1.

Activities

NEHRP's initial legislation and subsequent amendments did not define a specific role for NIST. In the 1980s, NIST's activities were "exclusively focused on the studies of performance of buildings through in-house experimental and analytical research."[30] The 1990 NEHRP reauthorization defined NIST's role as follows: "The National Institute of Standards and Technology shall be responsible for carrying out research and development to improve building codes and standards and practices for structures and lifelines."[31]

Increased funding since 1990 has allowed NIST to expand into new areas. Its current NEHRP-related work includes:[32]

1. Applied engineering research:
   - preparation of guidelines for testing and evaluation of seismic isolation systems,
   - development of design provisions for precast concrete connections and for seismic strengthening of concrete frame buildings,
   - testing of masonry walls to determine shear capacity, and
   - development of improved methods to predict the effects of ground motion on lifelines.
2. Code development and distribution, including technical support for model code adoption of the NEHRP Provisions.
3. Technology transfer (e.g., support of conferences and meetings for engineering research).
4. International cooperation, including technical and financial support for various meetings and exchange programs with other countries.

OTHER RELATED FEDERAL AGENCY ACTIVITIES

Several federal agencies in addition to the four primary NEHRP agencies spend many millions of dollars in earthquake mitigation. These efforts include evaluating the seismic safety of facilities and improving their seismic resistance, conducting earthquake-related research and development, and other efforts.[33] Although detailed agency spending data are not available, this non-NEHRP federal spending on earthquake-related research and development on upgrading the seismic resistance of facilities probably exceeds the $100 million spent annually by the four primary NEHRP agencies.[34] The contributions of many non-NEHRP agencies are summarized in table B-8.

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[30] Riley Chung, National Institute of Standards and Technology, personal communication, June 30, 1994.

[31] Public Law 101-614, sec. 5b5, Nov. 16, 1990.

[32] Federal Emergency Management Agency, *Preserving Resources through Earthquake Mitigation*, see footnote 21.

[33] David W. Cheney, Congressional Research Service, "The National Earthquake Hazards Reduction Program," 89-473SPR, Aug. 9, 1989.

[34] The last budget data were for the period ending 1987. Ibid., p. 20.

TABLE B-8: Summary of Federal Earthquake-Related Activities

Agency/department	Examples
National Aeronautics and Space Administration (NASA)	NASA conducts research and development (R&D) in basic earth processes. Its space-based geodesy program has enabled important advances in monitoring and characterizing crustal deformation and strain before, during, and after seismic events
National Oceanic and Atmospheric Administration (NOAA)	NOAA provides real-time tsunami warnings for the United States and its possessions and territories; the warnings are issued from two centers, located in Alaska and Hawaii In addition, NOAA's seafloor mapping and monitoring of marine earthquakes support improved understanding of offshore earthquake hazards and the reduction of tsunami risk. NOAA also disseminates earthquake and tsunami data through the National Geophysical Data Center.
Department of Energy (DOE)	DOE has conducted earthquake hazard research related to nuclear powerplants and waste disposal. DOE has upgraded the seismic resistance of many of its facilities, including its national laboratories and nuclear weapons production facilities. As part of its nuclear energy research programs, DOE has also studied ways to improve the seismic safety of new reactor designs.
Nuclear Regulatory Commission (NRC)	In the past, NRC has sponsored seismographic networks in the eastern United States to aid in analyzing seismic risks to nuclear powerplants. The commission has also conducted engineering research related to improving the seismic resistance of nuclear powerplants and waste disposal facilities.
Department of Defense (DOD)	DOD has a seismic safety program to ensure appropriate seismic safety of its facilities, and conducts seismic R&D with applications to other government and privately owned infrastructure. The Army Corps of Engineers, for example, addresses the seismic safety of dams. DOD also operates seismic stations for nuclear test monitoring and supports seafloor research (by the Office of Naval Research).
Department of Transportation (DOT)	DOT conducts seismic research in advanced earthquake-resistant design, construction, and retrofit of highway bridges through the American Association of State Highway and Transportation Officials specifications and guides of recommended practice; assesses DOT facilities to prevent interruption of vital functions; and provides immediate response after major earthquakes.
Bureau of Reclamation, Department of the Interior	The bureau is the lead technical agency for Interior's Safety of Dams Program. In addition to dam modifications, it conducts seismotectonic studies, operates three seismic networks in Colorado and Wyoming, and operates strong-motion instruments at dams and other critical facilities.
Department of Veterans Affairs (VA)	Since 1971, the VA has undertaken the seismic strengthening of its hospitals in areas of moderate and high seismic hazard.
Department of Housing and Urban Development (HUD)	HUD funds earthquake studies related to disaster response, damage assessment, and mitigation; conducts seismic risk assessments for HUD-assisted properties; develops seismic safety standards for such properties, as well as for manufactured housing; and provides major rebuilding and emergency housing assistance to earthquake-stricken communities
Centers for Disease Control and Prevention (CDC), Department of Health and Human Services	CDC conducts research on the health impact of natural and technological disasters in order to develop strategies to prevent or reduce future disaster-related health problems.

SOURCES: Office of Technology Assessment, based on David W Cheney, Congressional Research Service, "The National Earthquake Hazards Reduction Program," 89-473SPR, Aug. 9, 1989, and unpublished Office of Science and Technology Policy material For a further description of earthquake programs in these and other contributing federal agencies, see Federal Emergency Management Agency, *Preserving Resources Through Earthquake Mitigation*, FY 1993-94 NEHRP Report to Congress (Washington, DC December 1994), pp 131-170

Appendix C: International Earthquake Programs

C

Devastating earthquakes have been experienced all around the globe, at times with astounding loss of life (see table C-1). Figure C-1 illustrates recent world seismicity. Future occurrences of potentially damaging quakes are inevitable. As a result, many countries have mounted extensive research and development, hazard assessment, and disaster response programs related to earthquake hazards and seismic risk.

A comprehensive discussion of the many international mitigation programs and their achievements is beyond the scope of this report. Instead, this appendix briefly describes efforts under way in a few countries whose seismicity and mitigation practices may shed light on related U.S. efforts. It also outlines the framework that exists for cooperation and coordination among nations in understanding earthquake hazards and mitigating seismic risk.

To summarize, both Japan and China have sizable earthquake research and mitigation programs. Unlike the United States, however, the predominant focus of Japan's efforts is seismic monitoring and research applied toward predicting great earthquakes.

New Zealand also has a collection of efforts similar in scope, if not scale, to the U.S. national effort. One major difference is the inclusion of a government-sponsored earthquake insurance program and a move toward mitigating economic disruption along with threats to life safety. Several other countries have significant research programs or relevant data. For seismological or paleoseismological data from intraplate earthquakes, China and Australia are sources.[1] Russia, China, and Japan have data on potential earthquake precursors; Japan also has strong-motion data from subduction zone earthquakes and results from tsunami studies. In addition, Canada and the United States exchange data and analyses regarding seismic hazards in the west and east (e.g., subduction zone quakes in the Pacific Northwest and intraplate quakes in the northeastern United States).

[1] Few earthquakes that occur in relatively stable regions of continents have surface expression. Of the 11 historic intraplate earthquakes that have produced surface ruptures, five occurred in Australia since 1968. Michael Machette and Anthony Crone, "Geologic Investigations of Australian Earthquakes: Paleoseismicity and the Recurrence of Surface Faulting in the Stable Regions of Continents," *Earthquakes & Volcanoes*, vol. 24, No. 2, 1993, p. 74.

TABLE C-1: Selected Significant Earthquakes Worldwide

Location	Year	Magnitude	Impact
Northern China	1556	—	800,000 killed
Lisbon, Portugal	1755	—	60,000 killed, fire
San Francisco, California	1906	8.3	700 killed, fire
Messina, Sicily	1908	7.5	160,000 killed
Tokyo, Japan	1923	8.3	140,000+ killed, fire
Assam, India	1950	8.4	30,000 killed
Chile	1960	Mw 9.5	5,700 killed, 58,000 homes destroyed, tsunami
Alaska	1964	Mw 9.2	131 killed, tsunami
Northern Peru	1970	7.7	67,000 reported killed
Guatemala	1976	7.5	23,000 killed
Tangshan, China	1976	7.9	240,000-650,000 killed
Northern Iran	1978	7.7	25,000 killed
Mexico City	1985	8.1	10,000+ killed
Armenia	1988	6.8	55,000 killed
Loma Prieta, California	1989	7.1	63 killed, $5 billion to $10 billion damage
Northern Iran	1990	7.7	40,000 killed
Flores, Indonesia	1992	7.5	2,500 killed
Latur, India	1993	Mw 6.2	9,750 deaths
Northridge, California	1994	6.8	57 killed, more than $20 billion damage
Kobe, Japan	1995	6.8	5,500+ killed, more than $200 billion losses
Sakhalin Island, Russia	1995	Mw 7.0	Approximately 2,000 killed

NOTE A significant earthquake is one that registers a magnitude of 6 5 or more, or one that causes considerable damage or loss of life On average, 60 significant earthquakes take place around the world each year Mw represents moment magnitude, a measure of tha total seismic energy released

SOURCE: Office of Technology Assessment, based on Bernard Pipkin, *Geology and the Environment* (St Paul, MN West Publishing Co , 1994), and references cited therein, and William Ellsworth, U.S. Geological Survey, Menlo Park, personal communication, June 14, 1995

The United States is actively involved in several cooperative programs established to share expertise and data. Joint research and technology transfer projects have been especially useful to the spread of seismic zonation practices around the world.[2] (In a similar vein, technology transfer from Japan to Chile has been integral to the latter nation's advances in earthquake mitigation, for example, in tsunami studies.[3])

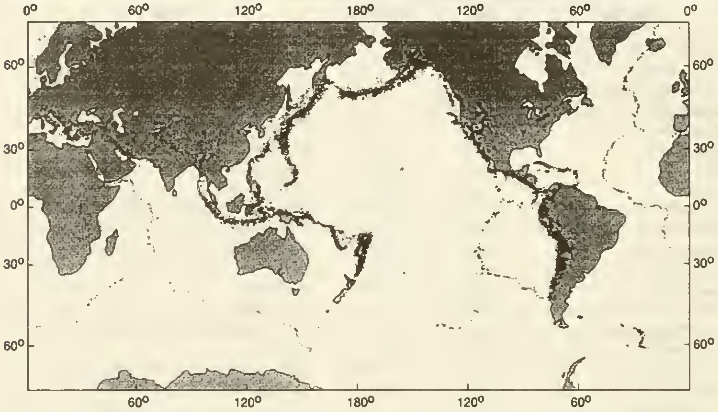
AUSTRALIA

Australia, a relatively stable continent far removed from the earth's plate boundaries, received

[2] Seismic zonation is the division of a geographic region into smaller areas or zones that are expected to experience the same relative severity of an earthquake hazard (e.g., ground shaking or failure, surface faulting, tsunami wave runup). Based on an integrated assessment of the hazard, built, and policy environments, resulting zonation maps provide communities with a range of options for ensuring resilience to earthquakes and sustainable development. U.S. Geological Survey, *Proceedings of the Fourth International Forum on Seismic Zonation*, July 14, 1994, Chicago, IL, and Aug. 30, 1994, Vienna, Austria, Open File Report 94-424 (Reston, VA: n.d.), appendix B, p. 1.

[3] See Maria Ofelia Moroni, "Technology Transfer on Earthquake Disaster Reduction Between Japan and Chile," *Bulletin of the International Institute of Seismology and Earthquake Engineering*, vol. 27, 1993, pp. 199-211. In 1960, a tsunami that originated off the coast of Chile caused nearly 1,000 deaths in that country and much destruction in Japan as well.

FIGURE C-1: Epicenters of 30,000 Earthquakes, 1961-67



SOURCE: Office of Technology Assessment, 1995, adapted from F. Press and R. Siever, *Earth*, Second Edition (San Francisco, CA: W.H. Freeman and Company, 1978), p. 412

a wake-up call with respect to urban earthquake hazards when a magnitude 5.6 (M5.6) earthquake struck Newcastle in December 1989. It resulted in about $2.86 billion (U.S.) in losses and 13 deaths.[4] The disaster led to increased studies of the region's intraplate quakes and a national program in seismic zonation.

The Australian Geological Survey Organization, in coordination with various state geological surveys and universities, conducts the national program in earthquake monitoring. With funding from the federal agency Emergency Management Australia and state governments, the Center for Earthquake Research in Australia (CERA) has completed seismic zonation maps for four of the largest cities (Sydney, Newcastle, Melbourne, and Brisbane and its environs). Maps for other urban areas are in progress.[5]

According to CERA, the outcomes of this mapping program have practical applications in many areas, including seismic code formulation, emergency management, and community education.[6]

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[4] John M.W. Rynn, "The Potential To Reduce Losses from Earthquakes in Australia," D.I. Smith and JW Handmer (ed.), *Australia's Role in the International Decade for Natural Disaster Reduction*, Resource and Environmental Studies No. 4, Journal of the Australian National University Center for Resource and Environmental Studies, 1991, p. 9.

[5] For a description of initial efforts, see John M.W. Rynn, "Mitigation of the Earthquake Hazard Through Earthquake Zonation Mapping: The Program for Urban Areas in Australia," *Proceedings of the Workshop Towards Natural Disaster Reduction*, June 27-July 3, 1993, Okinawa, Japan, S. Herath and T. Katayama (eds.) (Tokyo, Japan: International Center for Disaster-Mitigation Engineering, July 1994), pp. 115-136.

[6] John Rynn, Center for Earthquake Research in Australia, personal communication, June 7, 1995.

TABLE C-2: Canadian Organizations Involved in Earthquake Mitigation

Organization	Description	Activities
Geological Survey of Canada (GSC)	Agency of the Ministry of Natural Resources Canada	Seismic and strong-motion monitoring, hazard estimation; international cooperation.
National Research Council (NRC)	Established within the Ministry of Industry, Science and Technology	The agency's Canadian Commission on Building and Fire Codes promulgates the National Building Code.
Canadian National Committee on Earthquake Engineering	Committee with representation from GSC, NRC, and the private sector.	Develops seismic provisions for the National Building Code, advises the Canadian Commission on Building and Fire Codes, and provides advice to private industry on matters related to seismic hazard assessment for specific projects.
Emergency Preparedness Canada	Agency within the Ministry of Defence	Earthquake preparedness and response planning.

SOURCE Office of Technology Assessment, based on Peter Basham, Geological Survey of Canada, personal communicaton, Nov 24, 1994

Collaboration between Australia and other countries (e.g., neighboring developing nations in the South Pacific, countries in Southeast Asia, and South America, as well as the United States) is rapidly increasing.

CANADA

Canada has experienced several large, damaging earthquakes during its recorded history. Seismicity along its west coast is relatively well understood in terms of plate boundary convergence offshore. The sources of intraplate earthquakes in eastern Canada are less well known, but may be related to compressional stresses acting on localized zones of weakness in the crust.[7] Table C-2 shows the primary agencies and organizations participating in Canada's earthquake mitigation effort. According to the Geological Survey of Canada (GSC), it is the only federal agency concerned with seismological aspects of earthquake loss reduction, and the only Canadian agency with expertise in seismic hazard assessment.[8]

Canada's primary earthquake-related research goals are to: 1) understand the causes and effects of earthquakes well enough to be able to assess seismic hazards accurately throughout the country, and 2) improve knowledge of earthquake-resistant design and construction in order to provide an adequate level of protection against future earthquakes. Currently, a major research program is under way to produce new zoning maps for trial use, modification, and formal adoption in the year 2000 National Building Code of Canada. The existing code was adopted in 1985 and is based on

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[7] Dieter Weichert et al., "Seismic Hazard in Canada," *The Practice of Earthquake Hazard Assessment*, International Association of Seismology and Physics of the Earth Interior (Denver, CO: U.S. Geological Survey, 1993), p. 46.

[8] Unless noted otherwise, the material in this section is drawn from Peter Basham, Acting Director, Geophysics Division, Geological Survey of Canada, personal communication, Nov. 24, 1994.

probabilistic analyses of peak acceleration and peak velocity.[9] According to GSC, relatively little effort is devoted to microzonation, although some efforts have been undertaken as university research projects.

CHINA

Strong intraplate earthquakes frequently occur throughout China, which lies in the southeast part of the Eurasian plate. The seismicity is thought to be related to forces from the Pacific Plate to the east and the Indian Ocean Plate to the southwest. China's historic earthquake record extends back thousands of years; from 1831 B.C. to A.D. 1989, 17 great earthquakes, 126 major quakes, and almost 600 large earthquakes took place.[10] Because of their typically shallow depth and since relatively little building stock has been designed to resist shaking, severe damage and casualties are likely in the country's densely populated areas from large earthquakes (i.e., having magnitudes of 6 and higher).[11]

The Chinese government has a three-pronged effort to address seismic risks. Earthquake prediction, resistance, and emergency relief responsibilities are accorded to the State Seismological Bureau, the Ministry of Construction, and the Ministry of Civil Affairs, respectively.[12] A unified program is being assembled by the Chinese Ten-Year Committee, in cooperation with United Nations International Decade for Natural Disaster Reduction[13] (see table C-3.)

Prediction

The large-scale development of an earthquake prediction capability began after the 1966 Xingtai earthquake (M7.2), which resulted in 8,000 deaths.[14] Over the last couple of decades, a number of earthquake-monitoring systems have been set up in China's major seismic areas. The national network consists of six regional telemetry networks, 12 local radio telemetry networks, and 10 digital seismographic stations.[15] Data from these monitoring systems, and from other observations, support research in detecting precursors and correlating them with large earthquakes.

In 1975, hours before a M7.4 quake struck Haicheng, a series of foreshocks prompted residents to construct earthquake huts (temporary shelters adjacent to their homes) and local authorities to issue a warning of a major quake.[16] Even with these precautions, more than 1,000 people were killed. Without these measures, a much larger percentage of the 3 million people living in Haicheng might have died inside collapsed buildings.[17] However the Chinese prediction system has predicted earthquakes that did not occur and has failed to predict some that did. Several months after the Haicheng

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[9] With seven zones, the 1985 edition maps have a finer subdivision of zoning in moderate-risk areas and additional zones in the high-risk areas relative to the previous edition (1970). P.W. Basham et al., "New Probabilistic Strong Seismic Ground Motion Maps of Canada," *Bulletin of the Seismological Society of America*, vol. 75, No. 2, April 1985, p. 563.

[10] Xiu Jigang, "A Review of Seismic Monitoring and Earthquake Prediction in China," *Tectonophysics*, vol. 209, 1992, p. 325. See chapter 2 for description of earthquake severity scales.

[11] Ma Zongjin and Zhao Axing, "A Survey of Earthquake Hazards in China and Some Suggested Countermeasures for Disaster Reduction," *Earthquake Research in China*, vol. 6, No. 2, 1992, p. 241.

[12] Wang Guozhi, "The Function of the Chinese Government in the Mitigation of Earthquake Disasters," *Earthquake Research in China*, vol. 6, No. 2, 1992, p. 254.

[13] Ibid.

[14] Zongjin and Axing, see footnote 11, p. 243.

[15] The six regions covered are Beijing, Shanghai, Chengdu, Shenyang, Kunming, and Lanzhou. Ibid.; and William Bakun, U.S. Geological Survey, Menlo Park, personal communication, June 15, 1995.

[16] Cinna Lomnitz, *Fundamentals of Earthquake Prediction* (New York, NY: John Wiley & Sons, Inc., 1994), pp. 24-26.

[17] Bruce A. Bolt, *Earthquakes* (New York, NY: W.H. Freeman and Co., 1993), p. 194.

TABLE C-3: Earthquake Efforts by the People's Republic of China

Organization	Description	Activities
Ministry of Construction (MOC), Office of Earthquake Resistance	Established in 1967, MOC is concerned with emergency response, technical codes and standards, development of international cooperation, and education and training in earthquake engineering.	Funds proposals in earthquake resistance research for buildings and engineering structures; seismic response research for special works, structures, and equipment; strong-motion observation
State Seismological Bureau	Established in 1971, the bureau is responsible for central management of earthquake monitoring, prediction, and scientific and engineering research.	Plans and administers national seismological programs; conducts international cooperation and exchange programs in earthquake studies, performs field studies of societal responses to earthquake hazards and events. The bureau's Institute of Engineering Mechanics plays a key role in earthquake engineering research at the government level.
National Natural Science Foundation of China, Department of Architectural Environment and Structural Engineering	Supports research in basic theory, technical advances, and earthquake hazard mitigation.	Funds projects in hazard assessment; soil-structure interaction, structural dynamic response, seismic resistance of lifelines; base isolation and structural control; and earthquake site investigation and aseismic experimental technology.
Ministry of Energy, Science and Technique Development Foundation of Power Industry	Established in 1989 by the China Association of Power Enterprises in affiliation with the Ministry of Energy.	Awards grants to researchers and technological workers for studies related to hydroelectric, thermoelectric, and electric systems.

SOURCE: U.S Panel on the Evaluation of the U.S.-P.R.C. Earthquake Engineering Program, National Research Council Commission on Engineering and Technical Systems, *Workshop on Prospects for U.S.-P.R.C. Cooperation on Earthquake Engineering Research* (Washington, DC: National Academy Press, 1993), pp 8-10

quake, a M7.8 quake struck Tangshan, apparently without warning. Hundreds of thousands were killed.[18]

Seismic Zonation and Building Codes

In 1957, China adopted its first earthquake intensity scale, a 12-level scale similar to the Modified Mercalli Intensity scale, and initially focused its mitigation efforts on buildings in the highest hazard areas. In 1992, using data from recent earthquakes and geophysical studies, China promulgated a new edition of its seismic intensity zoning map. The Chinese zoning map reflects both subjective measures of intensity and probabilistic analyses of ground motion expected from future earthquakes. Grade 9 on the Chinese intensity scale is roughly equivalent to Zone 4 of the 1988 Uniform Building Code.[19]

The first seismic code was promulgated in China in 1974.[20] The Tangshan earthquake prompted

[18] The official estimate is approximately 250,000 deaths; however, unofficial estimates suggest that over 800,000 may have been killed.

[19] The Uniform Building Code is one of three U.S. model codes on which state and local seismic codes are based. See chapter 3.

[20] Hu Shiping, "Seismic Design of Buildings in China," *Earthquake Spectra*, vol. 9, No. 4, 1993, p. 704. The first draft, in 1957, was based on the Soviet code.

BOX C-1: Japan's Earthquake Prediction Program

Six agencies participate in Japan's earthquake prediction program. The Japan Meteorological Agency (JMA) collects seismological data and oversees Japan's prediction efforts. The Earthquake Assessment Committee, consisting of six eminent seismologists, is responsible for analyzing potentially anomalous data and reporting to the director of JMA a verdict of: 1) imminent danger, or 2) no danger.[1]

The Geodetic Council of Japan acts as an advisory body to the Ministry of Education, Science and Culture with respect to earthquake prediction, and oversees development of five-year program plans. Other agencies involved in the prediction effort include the Maritime Safety Agency, the Geographical Survey Institute, the Geological Survey of Japan, and the National Research Institute for the Earth Sciences and Disaster Prevention (part of the Science and Technology Agency).[2]

Now in its sixth five-year plan, the program has both harsh critics, which include an increasing number of Japanese scientists, and staunch defenders. Limited access to data, opportunity costs for other areas of earthquake research, and the program's narrow focus on the Tokyo region are among the motivations for criticism.

[1] Robert J. Geller, "Cash Falling Through the Cracks," *The Daily Yomiuri*, May 12, 1994, p. 6. The two options are designated *black* and *white* verdicts, respectively. A *gray* verdict, or statement of intermediate probability, is not permitted.

[2] Robert J. Geller, "Shake-up for Earthquake Prediction," *Nature*, vol. 352, No. 6333, July 25, 1991, pp. 275-276.

SOURCE: Office of Technology Assessment, 1995.

revision of this code; the effort was completed in 1978. The present code, promulgated in January 1990, was revised from the 1978 version by the China Academy of Building Research, along with other professionals.[21]

JAPAN

The Eurasian, Philippine Sea, Pacific, and North American Plates all converge in the vicinity of Japan. The relative movement of these plates causes Japan to experience strong to great earthquakes frequently, as well as face the threat of volcanic activity and tsunamis. The largest earthquakes have originated in the subducted Philippine Sea and Pacific Plates, although the havoc wreaked on Kobe by the 1995 Hyogoken-Nanbu earthquake reveals the hazard posed by shallow crustal quakes to densely populated cities.

Japan has a multipronged government program to address its many seismic risks. Unlike the United States, however, earthquake prediction is a primary focus of Japan's efforts to reduce losses from earthquakes.

Prediction

With spending on the order of $100 million per year—a figure that does not include salaries—Japan's prediction program receives funding comparable to the entire U.S. National Earthquake Hazards Reduction Program (NEHRP). Initiated in 1963, it is one of Japan's largest and oldest research projects[22] (see box C-1).

Pursuant to the 1978 Large-Scale Earthquake Countermeasures Act, 10 regions have been designated for special monitoring. The Kanto-Tokai Observation Network, for example, continuously

[21] Ibid., p. 705.

[22] Y. Ishihara, Office of Disaster Prevention Research, Japanese Science and Technology Agency, personal communication, June 16, 1995.

monitors crustal movements using more than 250 seismometers, strainmeters, and tiltmeters. In addition, 167 Global Positioning System stations operate in this area.[23]

The most recent five-year plan for the prediction program, adopted in 1993, continues intensive observation of the Tokai region, which is expected to experience the effects of a great earthquake on the nearby Suruga Trough.[24] Scientists hope to detect the onset of the quake by monitoring seismicity, strain, and crustal deformation. Previous major quakes on the Suruga and Nankai Troughs were preceded by rapid crustal uplift.

Building Codes and Engineering

Early in this century, Japan established one of the first seismic design codes based on the performance of certain buildings in Tokyo during the 1923 Great Kanto earthquake.[25] The years since then have seen many advances in earthquake engineering research, seismic codes, and construction practices, because of investment on the part of both the government and the private sector.

The most recent code went into effect in 1981.[26] The Japanese seismic design code differs from the current U.S. guidance document for building codes (i.e., the NEHRP Provisions[27]) in that it calls for a two-stage design process. The first phase follows an analysis approach similar to that used in the NEHRP Provisions; it is intended to preclude structural damage from frequent, moderate quakes. The second phase is an explicit assessment of the building's ability to withstand severe ground motions.[28] Design forces used in Japan also are typically significantly larger than in the United States. As a result, Japanese buildings tend to be stronger and stiffer than their U.S. counterparts, and will likely suffer less damage during moderate or severe shaking.[29]

Japanese construction companies annually spend a considerable amount on research and development, including testing of scaled building models in large in-house laboratories and research into passive and active control technologies. One result is that new technologies for seismic protection have been incorporated into new buildings at a faster rate than in the United States.[30]

The government's engineering research facilities include a large-scale earthquake simulator operated by the National Research Institute for the Earth Sciences and Disaster Prevention and used by other agencies. Future evaluation of the seismic performance of the built environment will likely be aided by the large set of strong-motion data obtained from the Hyogoken-Nanbu quake in January 1995; the data set includes near-fault re-

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[23] Ibid.

[24] Dennis Normile, "Japan Holds Firm to Shaky Science," *Science*, vol. 264, June 17, 1994, p. 1656.

[25] The United States adopted its first code shortly thereafter, in 1927.

[26] The Building Standard Law, proposed in 1977. For a description of Japan's seismic design methods, see Andrew Whittaker et al., "Evolution of Seismic Design Practice in Japan and the United States," *The Great Honshin Earthquake Disaster: What Worked and What Didn't?* SEAONC Spring Seminar Series, Engineering Implications of Jan. 17, 1995, Hyogoken-Nanbu Earthquake, May 25, 1995 (San Francisco, CA: Structural Engineers Association of Northern California, 1995), pp. 5, 10.

[27] Building Seismic Safety Council, *NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings* (Washington, DC: 1991).

[28] Whittaker et al., see footnote 26. Exemptions to this second phase of design are permitted only for buildings less than 31 meters in height and having the requisite materials and configuration. Andrew S. Whittaker, Earthquake Engineering Research Center, University of California at Berkeley, personal communication, May 29, 1995.

[29] Whittaker, ibid.

[30] David W. Cheney, Congressional Research Service, "The National Earthquake Hazards Reduction Program," 89-473 SPR, Aug. 9, 1989, p. 35.

cords that reflect rupture directivity and other effects encountered in the immediate vicinity of the fault.[31]

Response and Recovery

Within the National Land Agency, the Disaster Prevention Bureau was established in 1984 to develop disaster countermeasures through coordination with various ministries and agencies. The countermeasure framework has three primary parts: 1) making cities more disaster resistant, 2) strengthening disaster prevention systems (e.g., tsunami warning systems) and raising awareness, and 3) promoting earthquake prediction. One related effort has been to set up the Disaster Prevention Radio Communications Network to link agencies at the federal, prefectural, and municipal levels.[32]

The primary responsibility for disaster response rests with local-level governments that must ensure adequate water, food, and medical supplies. As witnessed in the 1995 disaster, however, Kobe's capabilities were overstretched, and some argue that mechanisms for federal intervention were inadequate. Whether or to what degree Japan's earthquake research, mitigation, and response programs will change as a result of the Kobe disaster is not yet clear. It must be noted that the intensive monitoring programs intended to support Japan's prediction capability cover but a small portion of the nation.

MEXICO

Off the western coast of Mexico, the North American Plate overrides the Cocos Plate. Historically, the Cocos Plate is the most active in the Western Hemisphere. This subduction zone has generated almost 50 earthquakes greater than magnitude 7 in this century, including the M8.1 quake that caused extensive damage and loss of life in Mexico City in 1985.[33]

Mexico currently has a national network of nine broadband seismic instruments linked by satellite, plus a number of regional networks.[34] Six additional broadband stations will be installed in 1995, one of them through a cooperative project with the U.S. Geological Survey.[35] Since late 1987, the National University's Geophysics Institute has operated a nine-station, short-period seismic network in the earthquake-prone state of Guerrero.

To record and assess severe shaking, strong-motion instruments are located throughout the Mexico City area. In cooperation with some U.S. universities and the Japan International Cooperation Agency, arrays of digital strong-motion networks are also operated in Guerrero.

Seismic zonation maps (e.g., maps of maximum Modified Mercalli Intensity, and peak acceleration and velocity) have been incorporated into the Mexican Building Code since the 1960s. In the 1985 quake, many high-rise buildings in an area of the city underlain by a former lake bed collapsed or were severely damaged. These buildings could not withstand the resonance effects induced by the long-period, long-duration shaking that occurred on soft soils. Microzonation has since been completed in the portions of Mexico City most susceptible to seismic wave amplification and liquefaction.[36] Other cities (e.g., Acapulco and

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[31] Earthquake Engineering Research Institute, *The Hyogo-Ken Nanbu Earthquake: January 17, 1995*, preliminary reconnaissance report (Oakland, CA: February 1995), p. 6.

[32] Disaster Prevention Bureau, Earthquake Disaster Countermeasures Division, *Earthquake Disaster Countermeasures in Japan* (Tokyo, Japan: National Land Agency, 1993), pp. 17-18.

[33] Bernard W. Pipkin, *Geology and the Environment* (St. Paul, MN: West Publishing Co., 1994), pp. 83-35. The earthquake catalog of the Geophysics Institute, National University of Mexico, contains 48 major quakes.

[34] U.S.Geological Survey, see footnote 2, p. 31.

[35] Ramón Zúñiga, Geophysics Institute, National University of Mexico, personal communication, June 12, 1995.

[36] U.S. Geological Survey, see footnote 2.

Guadalajara) have recently been included in the microzonation efforts. Based on recently collected data, new zonation maps are being prepared for Mexico as an extension of the Canadian-funded Seismic Hazard in Latin America and the Caribbean Project.[37]

NEW ZEALAND

New Zealand is located astride the boundary between the Australian and Pacific Plates; it is cut and deformed by many active faults and folds.[38] Not surprisingly, New Zealand has both an active research program in earthquakes and a longstanding effort to improve the seismic resistance of its built environment. In 1991, the nation adopted an integrated approach to natural hazards management, of which earthquake mitigation is a major part. Subject to certain constraints in the Resource Management Act of 1991 and Building Act of 1991, regional and local authorities are responsible for controlling land use and construction for the purpose of avoidance or mitigation of specific hazards.[39]

Research

The primary institutions conducting earthquake-related research include the Institute of Geological and Nuclear Sciences (IGNS), the Engineering Schools of Auckland and Canterbury Universities, and the Institute of Geophysics at Victoria University in Wellington. The latter has teaching and research programs in seismology, including seismic microzonation. Additional research is conducted by earth science departments in other universities and by some private civil engineering consultants.[40]

IGNS has six programs, funded at $27 million (U.S.) per year, which span the fields of geology, seismology, and engineering seismology.[41] For example, IGNS is currently pursuing a research program titled "Improvements to Earthquake Resistant Design" whose primary objectives are: improved modeling of strong ground motions; enhanced models of the effects of large earthquakes on buildings, other structures, and the natural environment; and improved antiseismic practices and technologies.[42]

The Earthquake Commission (EQC), which provides earthquake insurance for domestic property and contents, also funds approximately $340,000 (U.S.) of research per year. EQC, which administers the Natural Disaster Fund on behalf of the government, is the primary provider of natural disaster insurance to residential property owners.

[37] Zúñiga, see footnote 35. The Canadian International Development Research Agency funds the Seismic Hazard Project, now in its final phase. The project has two major components: 1) establish a uniform catalog of earthquakes for Mexico, Central and South America, and the Caribbean; and 2) develop probabilistic seismic hazard maps for this region. The Panamerican Institute of Geography and History, Organization of American States, oversees the multinational effort. James Tanner, Seismic Hazard in Latin America and the Caribbean Project, personal communication, June 16, 1995.

[38] Russ Van Dissen and Graeme McVerry, "Earthquake Hazard and Risk in New Zealand," *Proceedings of the Natural Hazards Management Workshop*, Wellington, NZ, Nov. 8-9, 1994 (Lower Hutt, New Zealand: Institute of Geological and Nuclear Sciences Limited, 1994), p. 71.

[39] See Christine Foster, "Developing Effective Policies and Plans for Natural Hazards Under the Resource Management Act," in *Proceedings of the Natural Hazards Management Workshop*, see footnote 38, pp. 34-35. One result of the recent legislation is increased demand on the part of regional and local authorities for seismic hazard and risk analyses.

[40] Unless noted otherwise, this section is drawn from personal communications with Warwick D. Smith, Chief Seismologist, New Zealand Institute of Geological and Nuclear Sciences, and John Taber, Institute of Geophysics, Victoria University of Wellington, Dec. 1, 1994.

[41] The Ministry of Research, Science and Technology provides the New Zealand government with policy advice, including recommended funding levels for different areas of research. Earthquake-related research is funded under the Earth Science and Construction categories, or *outputs*. The Foundation for Research, Science and Technology allocates monies for research programs within each output.

[42] A quarter of the program's funding comes from industrial sources. Description of the IGNS Program, "Improvements to Earthquake Resistant Design," provided by Don McGregor, Chief Scientist, New Zealand Ministry of Research, Science and Technology, personal communication, Jan. 17, 1995.

As of 1996, however, owners of nonresidential property will have to seek private coverage for buildings and their contents.

Roughly 25 percent of New Zealand's earthquake research is currently directed at microzonation. This work is included in both the Foundation for Research, Science, and Technology and EQC programs, and is also sponsored by regional and local governments.

Implementation

Under New Zealand's Resource Management Act, regional, district, and city councils are responsible for identifying and mitigating the effects of natural hazards. The councils exercise their duties with respect to earthquake hazards through zoning and microzoning, and by enforcing the New Zealand Building Code. This code is written in performance terms and was published in 1992, after preparation under the supervision of the Building Industry Authority. There were previous seismic loading requirements in building standards and other control documents dating back to 1935. The code requires building owners to maintain their buildings so that they continue to meet the earthquake resistance requirements that existed at the time the building was erected. In some of the more earthquake-prone areas, territorial authorities have required upgrading of older buildings to address possible seismic weaknesses that can be recognized.[43]

The New Zealand National Society for Earthquake Engineering is a nongovernmental organization with approximately 600 members, mostly civil engineers. The society plays a leading role in communication among parties interested in earthquake research, hazard and risk assessment, and mitigation via engineering solutions. Likewise, the Building Research Association maintains close ties with building control officials and manufacturers, who together expedite the introduction of research results into practice.[44]

Until recently, the main thrust of earthquake mitigation efforts in New Zealand was preventing building collapse and minimizing the hazard for occupants. However, this risk was considered to be less severe than for many other countries,[45] and today the reduction of economic disruption is receiving greater emphasis. Increasing the efficiency of restoration of infrastructure and lifelines is a primary consideration.[46]

For example, local councils in Wellington and later Christchurch established engineering exercises to coordinate efforts to sustain lifelines. They focused on the interdependence of these lifelines in urban areas to assess ways in which weakness might be identified and mitigated.[47]

RUSSIA

Microzonation of the largest cities in Russia and the former Soviet Union began in the 1950s, and seismic zonation maps were incorporated into the State Engineering Codes as early as 1957.[48]

Today, the primary institutions and organizations involved in Russia's earthquake efforts are:

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[43] Gerald Rys, Assistant Chief Scientist, New Zealand Ministry of Research, Science and Technology, personal communication, July 4, 1995.

[44] John Duncan, Research Director, Building Research Association of New Zealand, personal communication, Jan. 17, 1995.

[45] Reasons include: 1) ongoing implementation of simple antiseismic measures based on early colonial experiences in severe earthquakes, and 2) the fact that the majority of New Zealanders live in single-dwelling, typically wood-framed structures.

[46] Smith and Taber, see footnote 40.

[47] Interdependence relates to the effect of the outage of one utility service (e.g., power) on the time required by another service to recover. The lifeline effort also designated *critical areas*—that is, where a number of lifelines are vulnerable in one location (e.g., a bridge carrying water, gas, and power in addition to traffic). David Brundson, "Reducing Community Vulnerability to Earthquakes: The Value of Lifeline Studies," in *Proceedings of the Natural Hazards Management Workshop*, see footnote 38, p. 10.

[48] U.S. Geological Survey, see footnote 2.

the Ministry of Russian Federation for Civil Defense, Emergencies and Elimination of Consequences of Natural Hazards; the Interdepartmental Commission for Seismic Monitoring; and the Russian Academy of Sciences. Russia operates several seismic and strong-motion monitoring stations. However, nearly all are still equipped with analog instruments and transmission methods that limit the quantity and quality of data. The number of stations in operation has decreased in recent years due to lack of funding.[49]

In 1994, the Russian government approved the establishment of a new program to develop a federal system of seismological networks and earthquake prediction, with several objectives:

- seismic hazard assessment,
- prediction of strong earthquakes based on comprehensive analysis of geophysical and geodetic precursors,
- epicentral seismological observations,
- strong-motion data for improvement of seismic resistant design and construction,
- implementation of mitigation measures in areas where strong earthquakes are expected in order to evaluate their effectiveness, and
- development of methods for predicting human-triggered seismicity and for minimizing seismicity induced by mining or reservoirs.

The means to these ends include modernization of observation stations, data transfer and storage techniques, and improved coordination of the efforts of many ministries and agencies. As of late 1994, however, the government had not allocated any financial resources to implement the program.[50]

VEHICLES FOR COOPERATION AND COORDINATION

A number of organizations and other mechanisms foster the international exchange of ideas and practices in the area of earthquake research, mitigation, and response. For example, the U.S. Geological Survey (USGS) and the National Science Foundation (NSF) maintain close working relationships with Japan in earthquake seismology.[51] In addition, for many years, the United States and Japan have held joint workshops under the auspices of the United States-Japan Panel on Wind and Seismic Effects (see box C-2). The United States has established and renewed scientific protocols with the People's Republic of China, and with Russia and other members of the Commonwealth of Independent States. Cooperation between the United States and Taiwan, and between Latin American states, is ongoing, and there are many such efforts with other countries.

Japan also has established cooperative exchanges with many countries, as have some other nations (e.g., Canada and France). There are multilateral forums as well—notably the United Nations International Decade for Natural Disaster Reduction (IDNDR), established in 1990 to promote mitigation and cooperation worldwide.[52] Over the years, several regional programs have

[49] According to one reviewer, the disastrous Sakhalin Island earthquake of May 1995 illustrates the decline of Russia's earthquake program: the seismic monitoring network had been shut off, there was apparently no plan to retrofit the apartment buildings that collapsed, and the emergency response effort suffered from a shortage of resources. William L. Ellsworth, U.S. Geological Survey, Menlo Park, personal communication, June 14, 1995.

[50] Yu S. Osipov, President of the Russian Academy of Sciences, letter to V.F. Shumeiko, Chairman of the Federation Council of the Federal Assembly of the Russian Federation, Nov. 1, 1994, in "The Shikotan Earthquake of October 4(5), 1994," *Russia's Federal System of Seismological Networks and Earthquake Prediction*, Information and Analytical Bulletin, Special Issue No. 1, November 1994.

[51] Federal Emergency Management Agency et al., "National Earthquake Hazards Reduction Program: Five-Year Plan for 1992-1996," September 1991, p. 91.

[52] The IDNDR sought, in part, to promote: the integration of hazard reduction policies and practices into the mainstream of community activities; funding of additional research into the physical and social mechanisms of natural hazards and the disasters they precipitate; and elimination of constraints on the use of scientific and technical knowledge. National Research Council, *The U.S. National Report to the IDNDR World Conference on Natural Disaster Reduction*, Yokohama, Japan, May 23-27, 1994 (Washington, DC: National Academy Press, 1994), p. 1.

BOX C-2: United States-Japan Panel on Wind and Seismic Effects

The panel consists of 16 U.S. agencies, led by the National Institute of Standards and Technology, and six Japanese agencies. Over the years, the panel has

- held 25 annual technical meetings for prompt exchange of research findings,
- conducted more than 40 workshops and conferences on such topics as the repair and retrofit of structures,
- conducted cooperative post-earthquake investigations in Japan and in the United States,
- hosted visiting Japanese researchers and provided access for U.S. researchers to unique Japanese facilities, and
- organized cooperative research programs on steel, concrete, masonry, and precast concrete structures.

SOURCE Richard Wright, Director, Building and Fire Research Laboratory, National Institute of Standards and Technology, testimony at hearings before the Senate Committee on Commerce, Science, and Transportation, Subcommittee on Science, Technology, and Space, May 17, 1994, p 31

been established, including projects in the Balkans, countries adjacent to the Mediterranean Sea, and central and South America.[53]

In general, there is extensive cooperation with respect to the collection and sharing of earthquake data. With the Global Seismographic Network (GSN), earthquake source data are collected from and distributed to Europe, Latin America, Asia, and Australia.[54] The Global Geodetic Network uses high-resolution, space-based geodetic techniques to monitor crustal motion and deformation around the world. It is supported by NSF, the National Aeronautics and Space Administration, and the National Oceanic and Atmospheric Administration, and by agreements with some 45 countries to exchange data and coordinate activities.[55]

Post-earthquake investigations are another important means of collectively assessing the physical and societal impacts of damaging earthquakes and spurring further progress in mitigating against seismic risks. The Post Earthquake Evaluation Program, initiated in 1992 by USGS, the United Nations Educational, Scientific and Cultural Organization, and the Open Partial Agreement on Major Hazards of the Council of Europe, has the following objectives:

- create a mechanism for sharing information,
- strengthen interdisciplinary and interorganizational interfaces,
- increase the worldwide capacity for post-earthquake investigations, and
- foster the adoption of prevention, mitigation, and preparedness measures.[56]

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[53] Participating and sponsoring organizations include USGS, the U.S. Agency for International Development, the United Nations Educational, Scientific and Cultural Organization, and national governments. U.S. Geological Survey, see footnote 2, p. 11.

[54] Established by the Incorporated Research Institutions for Seismology (IRIS) and jointly operated with the USGS Albuquerque Seismological Laboratory, the University of California at San Diego's International Deployment of Accelerometers group, and other member universities, the GSN is a rapidly expanding network of high-quality seismographs installed around the world for the purposes of earthquake and nuclear test monitoring and related research. In addition to data from the GSN, the IRIS Data Management Center has recently begun collecting data from international seismic networks operated by the Federation of Digital Seismic Networks.

[55] Office of Science and Techology Policy unpublished material.

[56] U.S. Geological Survey, see footnote 2, p. 42.

D Appendix D: Acronyms

Caltech	California Institute of Technology
CDMG	California Division of Mines and Geology
CONCERT	Coordinating Organization for Northern California Earthquake Research and Technology
CUBE	Caltech-USGS Broadcast of Earthquakes
CUSEC	Central United States Earthquake Consortium
EWS	Early Warning Systems
FEMA	Federal Emergency Management Agency
GIS	Geographical Information System
GPS	Global Positioning System
IRIS	Incorporated Research Institutions for Seismology
M	magnitude
MMI	Modified Mercalli Intensity
Mw	moment magnitude
NCEER	National Center for Earthquake Engineering Research
NEHRP	National Earthquake Hazards Reduction Program
NEIC	National Earthquake Information Center
NIST	National Institute of Standards and Technology
NSF	National Science Foundation
NSN	National Seismograph Network
PASSCAL	Program for Array Seismic Studies of the Continental Lithosphere
R&D	research and development
REDI	Rapid Earthquake Data Integration
SAR	synthetic aperture radar
SCEC	Southern California Earthquake Center
UBC	Uniform Building Code
UNAVCO	University Navstar Consortium
URM	unreinforced masonry
USGS	U.S. Geological Survey
VLBI	Very Long Baseline Interferometry

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ROGER C. HERDMAN, DIRECTOR

Embargoed for Release

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U.S. REMAINS AT RISK FOR MAJOR EARTHQUAKE LOSSES

Damaging earthquakes will strike the United States in the next few decades, causing at the minimum dozens of deaths and tens of billions of dollars in losses. However, although earthquakes are unavoidable, the deaths and financial and social losses they cause are not. Wider use of known technologies and practices to reduce losses could save lives and money, says the congressional Office of Technology Assessment (OTA) in the report *Reducing Earthquake Losses*.

The report, released today, finds that although recent damaging earthquakes in the United States have occurred on the West Coast, much of the Nation --including the East Coast -- has experienced damaging earthquakes in the past, and is likely to do so in the future. And most areas are largely unprepared.

Although the federal government has had a research-oriented earthquake program since 1977, much of the United States remains at risk for significant earthquake losses. OTA reports that the federal earthquake program has improved our understanding of earthquakes and strategies to reduce their impact, but this understanding is often not applied. This "implementation gap" is in part the result of the federal program's strategy of supplying information, rather than using incentives or other methods to promote earthquake risk reduction.

OTA points out several steps that could improve the federal program. The first is to target efforts at areas likely to yield large benefits--for example research on improving ways to strengthen existing buildings and reduce building damage (rather than focusing exclusively on preventing collapse), and evaluation of implementation efforts. The second is to set tangible and explicit goals for the overall program, and to regularly measure progress toward these goals. The third is to consider changes in federal disaster assistance and related programs, to ensure that these programs promote implementation of known technologies and practices.

For copies of the 176-page report *Reducing Earthquake Losses* for congressional use, please call (202) 224-9241. To order copies for noncongressional use, indicate stock number 052-003-01431-9 and send your check for $12.00 a copy or provide your VISA or MasterCard number and expiration date to Superintendent of Documents, P.O. Box 371954, Pittsburgh, PA 15250-7974, [FAX (202) 512-2250].

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OTA is a nonpartisan analytical agency that will serve the U.S. Congress until OTA closes September 30, 1995. Its purpose is to aid Congress with the complex and often highly technical issues that increasingly affect our society.

Mr. BAKER. Dr. Abrams, thank you for being here today.

STATEMENT OF DR. DANIEL P. ABRAMS, PROFESSOR OF CIVIL ENGINEERING, UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN, REPRESENTING THE EARTHQUAKE ENGINEERING RESEARCH INSTITUTE, OAKLAND, CALIFORNIA

Mr. ABRAMS. Thank you. I represent the Earthquake Engineering Research Institute, known with the acronym, EERI, which was funded by the National Science Foundation and the National Institute of Standards and Technology to conduct an assessment of earthquake engineering experimental capabilities in the United States.

This was in response to the Public Law 103-74, which was the NEHRP Reauthorization Bill. And, Section 2 of that bill reads that, "The President shall conduct an assessment of earthquake engineering research and testing capabilities in the United States," and that the assessment should include the need for shake tables and other earthquake engineering research and testing facilities; two, options to cooperate internationally; three, projected costs for construction and maintenance of new facilities; and, four, options and recommendations to provide funding.

The assessment procedure consisted of bringing together approximately 65 of the nation's top earthquake engineering research experts, which was conducted in San Francisco at a workshop last July. And, I would like to present the seven recommendations that were boiled down from the two days of discussions at that meeting.

The first recommendation is that, "A comprehensive plan must be developed for experimental earthquake engineering research to effectively utilize existing laboratories and personnel, to upgrade facilities and equipment as needed, and to integrate new, innovative testing approaches into the research infrastructure in a systematic manner." And, this was a result of several discussions on the importance of research and testing in reducing earthquake losses that are itemized in my written testimony.

The second recommendation was in response to the needs for experimental research. And, that reads, "Experimental research programs must be pursued at an accelerated rate to advance the state of the art in seismic engineering and construction practices and, as a result, enhance public safety and reduce economic losses in future earthquakes."

And, it was found that seismic behavior of our buildings and lifelines is a very complex, scientific issue and that experiments were needed on large or full-scale systems to understand their behavior. Unlike airplanes or automobiles that can be tested fully under dynamic rates of loading before they are issued to the public, the majority of our buildings and bridges and lifelines have to wait for the first earthquake after they are built to be tested.

And, of course, this goes at a huge expense to the nation. The combined losses, both indirect and direct, for both the Loma Prieta and the Northridge earthquakes were approximately 5,000 times the annual budget for earthquake experimental research.

So, we don't want to have to wait for the earthquake to happen. We would like to solve our problems beforehand.

Recommendation 3, the highest priority of all the experts was that existing labs, laboratories, must be upgraded and modernized with new testing equipment. And, this was stated to utilize what we have to the fullest extent.

Because research funds are somewhat limited for earthquake engineering research, our laboratories are not fully utilized. Our present shake tables, of which there are five major ones in the U.S. and they are all of the small to medium caliber, are approximately 25 percent. That's the utilization.

Along with the upgrade—and the upgrade was estimated at about $60 million over a 5 to 10 year period—would be increased funds for experimental research to more fully utilize those facilities. And, that was estimated at approximately $50 million per year, which is approximately five times the present budget.

Recommendation 4 and 5 dealt with the need for new facilities. Recommendation 4 reads, "As a second highest priority, a series of new, moderately-sized regional centers must be created with unique and complementary capabilities."

And, this was to mean perhaps three to five centers of unique capability, such as large shaking tables or medium to large shaking tables, static test facilities, structural engineering research labs, in general. This was estimated at $180 million to $300 million per year but requires a more extensive feasibility study to narrow that down and with operating costs of approximately $100 million per year.

Costs to develop a single national test facility with a very large shaking table, one central place, was estimated in excess of $400 million, based on the Japanese experience with the large shaking table at Tadotsu, Japan, which cost them approximately $300 million dollars just for the shaking table, not the laboratory itself. This type of funding was thought to be on the high end of the scale.

And, before going further with that option, it was decided perhaps to have a detailed feasibility study to study the cost benefit ratios of having such a large investment in research.

Recommendation 6 dealt with funding options for new facilities. This was a change in the bill for the President.

And, the recommendation reads, "Future funding of earthquake engineering research must be sought through alternate, innovative sources." Present funding levels for earthquake engineering research were found to be insufficient to utilize present facilities at their full potential, to upgrade existing facilities or to develop new facilities.

Because of the impact of seismic damage on the national economy and on defense, continued and increased federal support of earthquake engineering research programs was found to be critical. However, alternate sources of funding would be needed as well.

And, there was some discussion at the workshop on exactly how to get these funds. Such approaches might include fees on construction, a value-added tax on constructed works, enhanced insurance incentives and government-mandated research on new forms of construction.

In general, the building industry has to support the research at an accelerated rate.

The last recommendation, Number 7, reads, "Existing cooperative research programs with other countries should be continued and new programs should be established where the sharing of testing facilities and the exchange of data and research results is mutually advantageous."

There are a number of existing cooperative programs underway with foreign countries on earthquake engineering research studies. There have been a number of international conferences and a number of cooperative programs with Japan, in particular, with large scale testing.

These should be continued. However, it should be noted that international programs by themselves should not be misconstrued as a replacement for upgrading of facilities in this country.

Thank you.

[The prepared statement of Dr. Abrams follows:]

Hearing on the

National Earthquake Hazards Reduction Program

Tuesday, October 24, 1995, 1:00pm
Room 2318 Rayburn HOB

Testimony of:

Dr. Daniel P. Abrams
Professor of Civil Engineering
University of Illinois at Urbana-Champaign

representing the

Earthquake Engineering Research Institute
Oakland, California

Subcommittee on Basic Research
Committee on Science
U.S. House of Representatives
Washington DC 20515

BACKGROUND

On August 22, 1994, the United States Senate passed an act to authorize appropriations for carrying out the Earthquake Hazards Reduction Act of 1977 for fiscal years 1994, 1995 and 1996 (Public Law 103-74). Section 2. of the Senate bill as reproduced below describes the need for a national assessment of earthquake engineering research and test facilities.

SEC. 2. EARTHQUAKE ENGINEERING ASSESSMENT.

(a) ASSESSMENT - The President shall conduct an assessment of earthquake engineering research and testing capabilities in the United States. This assessment shall include:

(1) the need for shake tables and other earthquake engineering research and testing facilities in the United States;

(2) options to cooperate with other countries that have developed complementary earthquake engineering and testing programs and facilities;

(3) projected costs for construction, maintenance, and operation of new earthquake engineering research and testing facilities in the United States; and

(4) options and recommendations to provide funding for the construction and operation of new earthquake engineering and testing facilities, including the feasibility and advisability of developing a comprehensive earthquake engineering research and testing program within the scope of the Earthquake Hazards Reduction Act of 1977.

(b) DEADLINE - The assessment required by subsection (a) shall be transmitted to Congress within nine months after the date of enactment of this Act.

The Senate bill was approved in the House of Representatives on October 4, 1994 and was signed by President Clinton on October 20, 1994.

In response to this directive, the National Science Foundation and the National Institute of Standards and Technology awarded a grant to the Earthquake Engineering Research Institute to conduct this assessment. This report summarizes results of this assessment and provides recommendations for future development of earthquake engineering research and test facilities in the United States of America. The expectation of preparing this report is that the President may use this information in preparing a response to the issues addressed in the Senate bill.

The assessment procedure consisted of bringing together sixty five of the nation's leading experts in earthquake engineering research to discuss the state of existing experimental capabilities and needs for the future relative to the four issues listed above. Twelve commissioned papers were presented to stimulate discussions in break-out groups on various topics related to existing and future research and testing capabilities, and needs for experimental earthquake research.

This executive summary provides condensed statements that reflect the general findings and key recommendations of the workshop participants. Additional recommendations and supporting discussions are given in the main body of this report.

ASSESSMENT FINDINGS AND RECOMMENDATIONS

The Importance of Research and Testing in Reducing Losses from Earthquakes

A significant reduction in economic and other losses from future earthquakes in the United States can be realized through an accelerated and coordinated national program of earthquake engineering research and testing. The direct benefits of such a program would include:

- improved knowledge of the complex phenomena controlling seismic performance of structures and lifelines;
- rapid development of reliable and cost effective design guidelines and standards, verified through research and testing, for the design and construction of new structures and for the evaluation and rehabilitation of seismically vulnerable and hazardous existing structures and lifelines;
- increased competitiveness and productivity of the U.S. construction industry through the introduction of new and high performance materials, structural systems, and construction procedures as well as of innovative engineering concepts for reduction of seismic risk;
- development of a technically sound basis for actions and policy decisions by government leaders, insurance brokers, owners and others; and
- an expanded base of trained design professionals, educators and researchers capable of addressing the serious technical challenges of reducing the risks posed by earthquakes.

To implement this earthquake engineering research requires the formulation of a comprehensive national program as well as systematic upgrading and augmentation of existing research and testing facilities. The cost of improved facilities and expanded support of experimental research will be a small percentage of the benefits accruing from this program for a *single*, moderate-intensity earthquake occurring in or near a highly developed urban region.

Several examples can be shown of how limited amounts of research have already improved seismic performance and reduced earthquake losses associated with buildings, bridges and lifelines. The dramatically improved responses of new versus older reinforced concrete bridges and buildings during the Northridge earthquake are but two statements of the efficacy of past NEHRP-funded research efforts. However, the poor performance of many older buildings and infrastructure systems, as well as of modern steel structures, and the tremendous economic losses and social disruption caused by earthquake damages to the built environment, vividly demonstrate the potential and need of a much more aggressive program of experimental research for minimizing losses associated with future earthquakes.

Development of a comprehensive earthquake engineering research and testing program within the scope of the Earthquake Hazards Reduction Act of 1977 is feasible and essential, and is strongly advised if the nation is to benefit fully from its research investment. Present human resources and the existing research infrastructure offer a foundation on which to base such as program. The existing NEHRP agencies can provide the impetus for development of a comprehensive program. Planning should be consistent with the objectives of the new National Earthquake Loss Reduction Program (NEP), and should include and encourage research conducted by coalitions and consortia of organizations from research, professional engineering and industrial sectors of our society.

Recommendation 1

A comprehensive plan must be developed for experimental earthquake engineering research to effectively utilize existing laboratories and personnel, to upgrade facilities and equipment as needed, and to integrate new, innovative testing approaches into the research infrastructure in a systematic manner.

The Need for Experimental Research

Seismic behavior of structures is complex, not only because of the erratic nature of the movements of the ground, but because the dynamic oscillations produced by these movements strain a structure well beyond the elastic range of behavior encountered under more common gravity and wind loadings. Everyday experiences of structural engineers cannot be relied upon to counter the extreme responses produced by earthquakes. Some response and damage patterns have yet to be discovered because of the short history of constructed works and the rapid evolution of building standards relative to the timing of major earthquakes. Thousands of buildings can be constructed before one learns of a deficiency that is common to them all, like the steel buildings affected by the Northridge earthquake.

Mathematical models for analyses of structural systems are generally much more simpler than the actual mechanisms they represent. Substantial difficulty exists in predicting repeated, cyclic deformations of a structure during a major earthquake. As a result, earthquake reconnaissance has been a primary means of validating and improving design methods. Unfortunately, this has proven to be a slow process, and lacks the quantitative aspects needed to improve engineering tools and judgment. Unlike laboratory experiments where the loading can be systematically controlled to examine various stages of behavior, actual earthquakes are events of uncontrollable intensity, frequency content, duration and location.

Laboratory and field studies investigating seismic response of structures are a fundamental part of earthquake engineering research, and must be pursued. Laboratory and field testing along with coordinated analytical and design research can allow us to systematically improve design methods and validate the performance of new structural systems and construction methods prior to a catastrophic earthquake.

Recommendation 2

Experimental research programs must be pursued at an accelerated rate to advance the state of the art in seismic engineering and construction practices, and as a result, enhance public safety and reduce economic losses in future earthquakes.

The State of Present Facilities

The state of experimental facilities for earthquake engineering research has not developed at a pace consistent with the needs for an improved understanding and awareness of earthquake hazards. In lieu of having more reliable and cost effective systems developed through advanced experimental studies, avoidable losses continue to reoccur after every damaging earthquake.

Past experimental research studies have led to remarkable improvements in seismic performance of structures. The excellent performance of new construction in recent earthquakes demonstrates the effectiveness of the research approach, and provides an indication of the potential of a much more aggressive experimental program for reducing losses in future events. However, earthquake engineering research and test facilities in the U.S. are outdated. Minimum capabilities necessary for testing components of major buildings, bridges and lifelines with confidence are lacking. Our laboratories are not equipped at levels available in countries with whom we must compete in a global market. For instance, the largest shaking table in the U.S. has a platform size of 20 feet by 20 feet which cannot be used to test full-size models of even the smallest structures, nor can it be used to subject them to ground deformations even approximating those representative of recent earthquakes. Moreover, many major U.S. laboratories are in poor condition and technically obsolete.

If experimental capabilities are not improved, the present rate of earthquake engineering research cannot possibly satisfy the demand to construct and rehabilitate structures and lifelines, to ensure public safety during earthquakes, and to mitigate losses from future catastrophic earthquakes. Strategic upgrading of existing core laboratories in the United States using state of the art equipment, innovative testing technologies, and minor capital improvements will significantly increase earthquake engineering research and testing capabilities. An implementation study is needed immediately to formulate a comprehensive plan balancing needs, relative contributions and upgrade costs of individual laboratories across the country.

Along with upgrading facilities, the volume of experimental research needs to be increased to exploit the potential of available personnel and laboratories, and to enhance the utilization of present facilities. A gradual and systematic investment in capital improvements should be matched with a steady increase in support for experimental research.

The capital costs for upgrade of facilities in existing U.S. laboratories are estimated at $60 million spread over a five to ten year period. The costs of research, operation and maintenance of these facilities are estimated at $40 to $50 million per year.

Recommendation 3

As the highest priority, existing laboratories must be upgraded and modernized with new testing equipment.

The Need for New Facilities and Projected Costs

New facilities and procedures are needed to test representative specimens of large-scale buildings, bridges and lifelines. The minimum credible portion of an actual structural system and the minimum acceptable scale of specimen set the minimum dimensions of earthquake simulation facilities at a size much larger than presently exists in the United States.

Innovative earthquake simulation techniques should be considered such as the use of a series of small, multiple shakers in lieu of a single large shaking table. Improved methods and equipment for field and on-site testing should also be developed.

A series of moderately-sized new laboratories with unique and complementary testing capabilities are required. Such facilities need not be centralized, but could be constructed cost effectively at regional centers close to existing laboratories where personnel and ancillary equipment already exist. Capital expenditures for all regional centers are expected in the range of $180 to $300 million with total operating budgets in excess of $100 million per year. Estimating costs for constructing compatible, special purpose large-scale testing facilities requires detailed feasibility studies based on development of a future comprehensive national plan for experimental research.

Recommendation 4

As a second highest priority, a series of new, moderately-sized regional centers must be created with unique, and complementary capabilities.

Costs to develop a single national testing facility with a large shaking table and/or large reaction wall are estimated in excess of $400 million. Annual operating costs for a national facility are estimated in excess of $100 million.

These figures are based on development costs for a large-scale earthquake simulation facility in Tadotsu, Japan where a single 49-foot square shaking table cost the Japanese approximately $300 million in present dollars. Annual operational costs for this large-scale test facility are approximately one third of the development cost. Cost estimates are adjusted for development in the less expensive U.S. construction market.

A single national facility with a large shaking table and/or a large reaction wall may not have as significant an impact on earthquake hazard reduction as a series of regional centers of moderate size, each with special capabilities. The large capital expenditure and operating cost, and lengthy development time associated with construction of a large facility, may not be commensurate with benefits obtained by doing such large-scale experiments. For a fraction of the operating costs associated with a single large facility, a number of research and testing programs could take place at regional centers and smaller institutions that could possibly yield a larger amount of research information than at a single, large facility.

Recommendation 5

A detailed feasibility study should be undertaken to estimate benefit-to-cost ratios associated with development, maintenance and operation of a single, national test facility.

Funding Options for New Facilities

Present funding levels for earthquake engineering research are insufficient to utilize present facilities at their full potential, to upgrade existing facilities, or to develop new facilities. Because of the impact of seismic damage on the national economy and on defense, continued and increased federal support of earthquake engineering research programs is critical. However, alternate sources of funding will be needed as well.

The U.S. construction industry is extremely competitive, and does not commit to funding of research unless problems arise that pose a threat to proprietary markets, such as the concern over steel weld failures following the Northridge earthquake. Even under these circumstances, the contribution of the U.S. construction industry is small.

If industry is to participate in, and provide support for research, incentives and requirements will need to be changed or developed. Creative approaches for developing research funds are needed if seismic mitigation is to proceed at acceptable levels. Such approaches might include fees on construction, a value added tax on constructed works, enhanced insurance incentives, and government mandated research on new forms of construction. In general, building owners and construction companies need to develop an improved awareness of earthquake hazards to appreciate the worth of enhanced research programs on performance of their structures.

Recommendation 6

Future funding of earthquake engineering research must be sought through alternate, innovative sources.

The Role of International Cooperation

Existing cooperative programs between the United States and other countries have proven to be beneficial in the past, and should be continued. Multinational cooperation between the U.S. and other countries should be pursued for funding projects of mutual interest, for exchange of personnel, and for effective utilization and sharing of specialized equipment and facilities. The model set forth by the European Community for multinational coordination of research should be considered.

Cooperative initiatives should be strengthened following destructive earthquakes in foreign countries to broaden the educational component associated with reconnaissance studies and international exchange of data and research results.

Because of differences in construction methods and the need to conduct academic research near home institutions, international programs should not be misconstrued as a replacement for upgrading of facilities and development of research programs in the U.S.

Recommendation 7

Existing cooperative research programs with other countries should be continued, and new programs should be established where the sharing of testing facilities, and the exchange of data and research results is mutually advantageous.

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PREFACE

An assessment of national research and test facilities for earthquake engineering research was done in response to a need expressed in the NEHRP reauthorization act of October, 1994 (Public Law 103-374). With sponsorship of the National Science Foundation and the National Institute of Standards and Technology, the Earthquake Engineering Research Institute (EERI) conducted the assessment during a five-month period starting in May of 1995. This report summarizes this assessment.

The study was assigned to the EERI Experimental Research Committee whose chair served as chair of the assessment Steering Committee. The Steering Committee included six individuals in addition to the chair who represented experimental earthquake engineering researchers as well as engineers who rely on experimental data. A Project Manager was appointed by the Steering Committee to assist with coordination of a workshop and preparation of this report.

The primary element of the assessmeni . as a workshop which was held on July 31 and August 1, 1995 in San Francisco. Sixty-five invited participants representing the earthquake engineering research and professional community attended. Authors of twelve commissioned papers presented their conclusions and recommendations on various topics related to earthquake engineering research and test facilities. This was followed by focused discussions on six specific topics in break-out sessions (three per day) of nominally twenty experts each. Summaries of discussion groups were presented at plenary sessions where further discussion took place.

The assessment was done with the expectation that the President may use this information in preparing a response to the issues addressed in Public Law 103-374. Specific statements are made with respect to the need for upgrading and modernizing existing testing facilities in the U.S., the need for new national research and test facilities in the U.S., options for multinational cooperation, projected costs for construction, operation and maintenance of new research facilities, options for funding of future experimental earthquake engineering research, and the feasibility of developing a comprehensive national research program. Recommendations have been gleaned from statements made in the workshop discussions as well as from the invited papers. Though no formal consensus process was followed, the recommendations and priorities stated herein represent the general sentiments of the workshop participants.

The recommendations identify future actions, if acted upon, that will significantly reduce earthquake losses by improving the earthquake engineering research and testing capability in the United States as it enters the twenty-first century.

Daniel P. Abrams
Chair, Steering Committee

James E. Beavers
Project Director

ASSESSMENT OF EARTHQUAKE ENGINEERING RESEARCH AND TEST FACILITIES

1. Background and Purpose

Damage to buildings, bridges and lifelines during the October 17, 1989 Loma Prieta earthquake and the January 17, 1994 Northridge earthquake resulted in substantial economic loss. Estimates of over $50 billion in damage and business losses were reported for these two urban earthquakes. In addition over a 100 deaths were attributable to the pair of events. Future earthquakes of larger magnitude than either of these two events are predicted to occur in the United States in the next thirty years, and economic losses are expected to well exceed those incurred in 1989 and 1994.

With the proper application of engineering principles, fatalities and economic losses resulting from moderate and strong earthquake motions can be reduced. This requires improved knowledge of how structures and lifelines behave when excited by ground motions during earthquakes. Unlike automobiles or aircraft that are proof tested repeatedly at full scale before being issued to the public, the seismic safety and performance of buildings, bridges and lifelines cannot be verified with full-scale prototype tests because of their large size and complexity relative to available testing facilities. Similarly, the large number of different types of structural systems, configurations and materials makes it economically infeasible to proof test all structures. Instead, relatively simple methods based on theoretical considerations, and tests of materials and small scale members are generally used in design.

Advanced computer simulations for estimating dynamic response of complex buildings, bridges or lifeline systems cannot be relied on with confidence because programmed algorithms cannot be confirmed without tests. Because of limitations in available testing hardware, and the unduly extrapolations that must be made between idealizations and dynamic response of actual structures, our knowledge and confidence in seismic response of structures is limited. Because of this uncertainty, the degree of seismic safety for most of the existing structures and lifelines in the United States cannot be precisely estimated. We only learn, generally too late, when we suffer a major earthquake.

In an effort to bring this issue to a national forefront, the NEHRP Reauthorization Bill of 1994 (Public Law 103-374) requires that the President shall conduct an assessment of earthquake engineering research and testing capabilities in the United States. As stated in the act: *This assessment shall include--- (1) the need for shake tables and other earthquake engineering research and testing facilities in the United States; (2) options to cooperate with other countries that have developed complementary earthquake engineering research and testing programs and facilities; (3) projected costs for construction, maintenance, and operation of new earthquake engineering research and testing facilities in the United States; and (4) options and recommendations to provide funding for the construction and operation of new earthquake engineering and testing facilities, including the feasibility and advisability of developing a comprehensive earthquake engineering research and testing program within the scope of the Earthquake Hazards Reduction Act of 1977.*

According to Rep. George Brown, Jr. (D-California), then Chairman of the House Science Committee, which has jurisdiction over earthquake research: *This assessment will address the growing concern that U.S. testing of building designs and construction methods cannot keep pace with the demand to construct such structures and ensure public safety during earthquakes.*

Since the NEHRP Reauthorization Bill was signed into law, the Hyogo-Ken Nanbu earthquake occurred near Kobe Japan on the first anniversary of the Northridge event. Observations of severe damage in a country known for its stringent seismic standards underscored the need for further earthquake engineering research. Casualties in Kobe exceeded 5000, and economic losses from this single event are estimated to exceed $200 billion, or one percent of Japan's gross national product. The extent of damage to the national infrastructure of Japan was severe with the collapse or damage of structures and lifelines needed for housing, business, industry, transportation and trade. Much of this loss could have been prevented if experiences with strong shaking of these structures could have been developed in a controlled scientific manner before the disaster. In such case, a systematic plan of rehabilitation could have been implemented to mitigate the earthquake hazard posed by existing structures and lifelines, and to avoid compounding this problem by constructing new buildings with undetected vulnerabilities.

In response to Public Law 103-374, the National Science Foundation and the National Institute of Standards and Technology (two of the NEHRP federal agencies) awarded a grant to the Earthquake Engineering Research Institute to perform an assessment of national earthquake engineering research and test facilities. To give structure to the assessment study, the same issues were addressed as given in the public law. This report is a summary of this effort, and has been prepared in anticipation of being used as reference material for the President's assessment.

2. Past Assessment Efforts

As noted below, previous assessment efforts on earthquake engineering research and test facilities date back to 1973. References for each effort are given in Section 4.

1. *NRC/NAE/NSF Workshop on Simulation of Earthquake Effects on Structures*, San Francisco, CA, September 1973.
2. *EERI Workshop on Experimental Research Needs*, Los Altos, CA, November 1982.
3. *NRC Study on Earthquake Engineering Facilities and Instrumentation*, San Francisco, CA, March 1984.
4. *NBS National Earthquake Engineering Experimental Facility Study, Phase I - Large Scale Testing Needs*, Gaithersburg, MD, November 1986.
5. *NRC Review of NBS Phase I Survey on Large-Scale Testing Needs*, NRC Committee on Earthquake Engineering's Advisory Panel, Spring 1986.
6. *US-PRC Workshop on Experimental Methods*, Tongji University, Shanghai, November 1992.
7. *US-Japan Seminar on Structural Testing Techniques: Development and Future Dimensions of Structural Testing Techniques*, Honolulu, HI, June 1993.

One common thread in all of these prior assessments was an expressed need for improvements in experimental methods and facilities. Each study emphasized the need for large-scale testing to provide information regarding structural behavior of actual structures during earthquakes.

One recommendation from the 1973 NRC/NAE/NSF study was that a few (two to four) medium size (20 to 40 ft.) shaking tables should be built and stationed around the country. The participants thought that each table should be considered a national facility, designed with different characteristics of motion (one to six components), frequency range, level of acceleration, and geometric configuration. As stated in 1973, these tables should be operational in the next five to ten years. No immediate need was evident for the construction of a large-size table, say the 100 foot by 100 foot size, however, the possibly of a need for a large shaking table was perceived in perhaps the next seven or eight years.

The 1982 EERI workshop emphasized the need for a shaking table that is approximately 50 feet by 25 feet, and the establishment of regional centers with medium-sized facilities that are available to university researchers. In addition, smaller satellite laboratories would feed into the regional centers.

The two bilateral workshops on experimental methods in earthquake engineering held with the Chinese in 1992 and with the Japanese in 1993 provided specific resolutions regarding testing technology, and continued to emphasize that improvements in experimental methods were needed.

3. Assessment Procedure

The procedure for conducting the assessment was to bring together over sixty of the nation's leading experts in earthquake engineering research and practice for a two-day workshop. Through detailed discussions on an assortment of technical issues, specific recommendations were made. A set of twelve commissioned papers were presented at the workshop to stimulate discussions among participants, and are summarized in Appendix A. Details of the workshop such as the program, list of invited participants and discussion group assignments are given in Appendix B.

The following sections present summaries of responses to various questions in six subject areas (see Table 1) that were expressed by groups of nominally twenty participants (see Appendix B.2 for listing of participants by discussion group). Following each discussion group meeting, summaries were presented to a plenary session of nominally sixty experts for their response and further discussion. The statements that follow represent a general agreement from these plenary discussions, and constitute the basis for the recommendations.

Table 1

Discussion Group Topics

Discussion Group	Topic
A	Evaluation of Existing Facilities
B	The Need for New Earthquake Test Facilities
C	Development of a Comprehensive National Research Program
D	Projections of Future Research Capabilities and Results
E	Options for Multinational Cooperation
F	Operation and Maintenance of New National Facilities

4. Evaluation of Existing Capabilities

4.1 Identify existing research and testing facilities in the United States, and categorize them with regard to function, versatility, capacity, useful life, etc.

The capability of earthquake engineering research and testing facilities has improved significantly since the 1973 NRC/NAE/NSF Workshop. For example, the two shaking tables in operation in 1973 (at the Universities of California and Illinois) have been augmented with an additional fifteen shaking tables of various sizes at laboratories across the nation. Today, over thirty institutions have some sort of testing facilities that are used for earthquake engineering research.

In terms of major facilities, there are presently in the U.S. five shake tables, three reaction walls, four geotechnical centrifuges, and sixteen floor reaction systems. In the rest of the world, there are fourteen shake tables (twelve in Japan), seven reaction walls (six in Japan), eleven geotechnical centrifuges, and twenty floor reaction systems of the same size or larger. Following the 1995 Kobe earthquake, the Japanese government and construction industry are examining the need for an increase in large-scale shaking tables, reaction walls and loading devices.

The largest shaking tables in the U.S. are at the University of California at Berkeley (20 ft. x 20 ft.), the State University of New York at Buffalo (12 ft. x 12 ft.), the University of Illinois at Urbana-Champaign (12 ft x 12 ft), the U.S. Army Construction Engineering Research Laboratory (12 ft. x 12 ft.) and the University of California at San Diego (10 ft. x 16 ft.), however, they are considered as small to medium sized tables. The payload capacity of these tables range from 15,000 to 120,000 lbs. Recent upgrades to the tables at Berkeley and USA CERL provide capability to excite test structures with three-dimensional earthquake motions.

Smaller shaking tables are in operation at ANCO, Cornell University, the California Institute of Technology, ETEC, Georgia Institute of Technology, Rice University, Stanford University, the University of California at Berkeley, the University of Southern California, Westinghouse Electric Company, and Wyle Laboratories. New tables are being acquired at the University of Nevada at Reno and the University of California at Irvine.

Static test facilities with reaction walls higher than 30 feet exist at the Budd Company, Lehigh University, National Institute of Standards and Technology, the University of California at Berkeley, the University of California at San Diego, and the University of Minnesota. Lower reaction walls with three-dimensional loading capability exist at the University of Texas at Austin, the University of Michigan and the National Institute of Standards and Technology. In contrast, at the Building Research Institute in Tsukuba Japan, a reaction wall with a height of 82 feet has been used to test full-scale seven story buildings. In addition, there are numerous structural engineering laboratories in Japan with reaction walls comparable to the largest available in the U.S.

Geotechnical centrifuges with earthquake simulators presently exist at the California Institute of Technology, Rensselaer Polytechnic Institute, the University of California at Davis, and the University of Colorado at Boulder. New centrifuges are being acquired at the Waterways Experiment Station and at Princeton University. Because centrifuges were installed much later than structural engineering test facilities, upgrade of them is not as high of a priority at present.

In general, most facilities have been utilized far less than they could if sufficient research funds were available. The current utilization of many U.S. shaking tables is approximately 25%. This under utilization is not because of a lack of technical problems to be solved, but because of limited funds.

4.2 What are the limitations of using reduced-scale models of structures, or testing at static rates?

Reduced-scale models can be used to verify and develop analytical models for determining global response, and to help understand local mechanisms observed in much more costly large-scale tests.

Reduced-scale models cannot reproduce many modes of nonlinear behavior of a prototype structure. Large-scale test specimens are needed to observe phenomena such as weld fracture in steel structures or bond-slip of reinforcing bars in a concrete or masonry structure. Moreover, reduced-scale models may not be able to physically represent prototype construction. Properties of materials may be drastically different at a reduced scale (e.g. notch toughness in steel specimens and confinement effects in reinforced concrete specimens).

The interaction of structural, architectural and mechanical systems must be best tested in a full-scale specimen because the details of construction defy modeling at a reduced scale.

Full-scale testing is required for ultimate validation of new design provisions.

Strengths and stiffnesses are known to increase with strain rate making results of static tests conservative. However, some types of structural elements tend to become more brittle as they are loaded dynamically reversing this trend.

The distribution of lateral forces changes continually during dynamic loading. This effect can be modeled using the pseudodynamic method, however, loading rates need to be sufficiently fast so that stiffnesses will not reduce artificially during the load duration.

4.3 How have earthquake hazards been reduced with past experimental research?

Past research has provided a major contribution to the development of new structural systems and design codes. The impact of code improvements have been demonstrated with the superior performance of modern buildings and bridges in the recent Loma Prieta, Northridge and Kobe earthquakes.

The practice of earthquake engineering has improved significantly as a result of research. The development of new structural systems such as ductile moment-resisting frames, coupled shear walls, and eccentrically braced frames, and the advent of new concepts for reducing seismic demands on structures (e.g. base isolation and passive damping) is very much a result of experimental research.

Most of the new knowledge on structural performance has been derived from experimental studies in addition to field observations and analytical models.

4.4 Project how the state-of-the-art in earthquake engineering will be advanced if experimental capabilities in the United States remain the same.

If capabilities remain the same, the present pace of experimental research will decline steadily because more efforts must be directed at maintenance of aging equipment. Studies will continue to rely primarily on static tests of components, and assumptions will continue to be made regarding relations between loading rates and scales. Confidence levels will remain low with respect to dynamic characteristics of structural systems until data is provided by a future earthquake of damaging intensity.

5. The Need for New Earthquake Engineering Test Facilities

5.1 What types and quantity of experimental research needs to be done to keep pace with the demand to construct engineering structures and ensure public safety during earthquakes?

The Loma Prieta, Northridge, and Kobe earthquakes caused extraordinary damage in urban areas where the performance of many engineered structures was poor. These recent earthquakes caused unacceptable infrastructure performance which could have been prevented by an understanding resulting from experimental research, full and large-scale experimentation, and proof or performance testing of structural systems and components. An impediment to rehabilitation of potentially deficient structures is that evaluation and retrofit procedures have not been verified with regard to their reliability and cost effectiveness.

Large structures, such as bridges and buildings, require large-scale experimental studies to understand their behavior during seismic excitation. Emerging aseismic systems such as active and passive energy dissipation systems also demand proof testing using large-scale experiments. Structures, components and their interactions for large industrial facilities such as chemical plants, power generation facilities and lifeline facilities require large-scale experimentation to fully understand their seismic behavior.

Large-scale research and testing facilities can address the types of experiments as listed below. The listing is not exhaustive. Examples are given to demonstrate the types of problems that can be explored if large-scale test equipment were available.

- Tests on building and bridge components and systems to define behavioral characteristics that need to be known for development of new engineering procedures for newly constructed structures, rehabilitation of undamaged structures prior to future earthquakes, and repair of damaged structures following earthquakes.
- Tests on building structures to define performance limit states for improved economical design, and loss estimation.
- Static and dynamic testing of three-dimensional structural systems to define interactions between components.
- Full-scale static tests of building structures and half-scale tests of bridge structures to verify scaling relations with smaller scale models.

5.2 What are the needs for small, medium and large, and multiaxis shake tables in the United States?

A high priority should be assigned to upgrading and maintaining the small and medium-sized shaking tables currently in operation. Most of these tables had their origins in the 1960's and 1970's, and need to be upgraded with more modern operating systems, and then maintained in a state of high readiness and availability.

Earthquake simulation testing facilities with the capability to test large structures are necessary to further explore earthquake mitigation strategies and prevent undesired economic consequences of future earthquakes. One large facility is needed to test structures with plan dimensions on the order of 50 feet. In addition, two regional shaking table facilities are needed where structures of approximately one half this size can be tested. The most recent technologies should be incorporated into the design of these tables and operating systems. Alternate approaches should be used in the development of these earthquake simulators to reduce cost. For example, multiple small-sized tables may be linked together in synchronization to excite a large-scale specimen with identical motions at its base. The same tables could be used in a different configuration to subject long-span bridge structures or piping systems to multiple excitations.

5.3 What are the needs for other earthquake engineering research and testing facilities in the United States, and how might they be used to reduce earthquake hazards?

Not all tests need to be done using a shaking table. Research and testing facilities other than shaking tables are essential elements of a complete national research and test program, and may include strong walls and reaction frames, and portable servohydraulic actuators for static loading of test specimens in the laboratory or in the field. These types of equipment can be used in harmony with shaking tables to develop a comprehensive understanding of the seismic behavior of structural systems and components.

A high priority should be assigned to preserving existing capabilities through equipment upgrades and regular maintenance so that availability and reliability remain high.

A second high priority should be to supplement existing research and test facilities with the following equipment.

- Two new strong walls for static testing of full-scale buildings up to eight stories in height.
- Several small strong walls for static testing of full-scale buildings up to two stories in height.
- Field testing equipment for loading to failure of actual buildings and bridges that are scheduled for demolition.
- Facilities for testing large-scale buried pipes and foundation piles that can be used in conjunction with a large shaking table.

5.4 What is an ideal combination of shaking tables (large, medium and small), large-scale reaction walls, field test equipment, instrumented actual structures, etc.?

Damage in recent earthquakes has demonstrated the need for a comprehensive set of experimental facilities nationwide. Not only are new shaking table facilities needed as noted in Section 5.2 but also the test equipment as noted in Section 5.3 are required. Development of new dynamic facilities should occur in concert with development of new static facilities as well to obtain an optimal blend of capabilities for the expenditure.

The ideal combination of static and dynamic test facilities should be determined through development of a comprehensive national plan for earthquake engineering research.

6. Development of a Comprehensive National Research Program

A quick assessment of the needs to allow the existing institutions and research teams to function effectively indicated that there was a critical need for modernizing and maintaining the physical facilities that are now available.

The national research budget should be based on the needed research in each particular technical area. An estimate of $40 to $50 million per year was made for earthquake experimental research in all areas including structures, geotechnical and lifeline research. In order to carry out this work in existing laboratories, an initial upgrade of facilities was estimated at $60 million.

- Progress toward solving earthquake engineering problems was not being hindered necessarily by lack of testing facilities, but rather by insufficient funding of research projects. Any funds available should be used with a gradual and systematic investment of capital improvements and a steady increase in the number and value of research projects in the laboratories selected for improvement. Such funding would allow the full capacity of the nation's experimental facilities to be developed, provide training for the next generation of researchers and laboratory staff, and represent a sustainable research effort.

6.1 If a regional network of earthquake engineering laboratories were to be developed, what division of capabilities between laboratories would be the most advantageous?

The need for a large-shaking table cannot be assessed until the capabilities of present U.S. shaking tables currently being upgraded or installed are fully understood. For example, the new modular shaking table concept soon to be developed at the University of Nevada needs to be implemented before judgments can be made regarding the feasibility of having a large-scale shake table such as the one at Tadotsu Japan.

A number of reaction wall facilities presently exist in the U.S. but may lack either the lateral-load capacity, height or multiaxis capability to be used for some large-scale testing needs. A high priority should be assigned to evaluating the need for additional reaction wall facilities relative to the earthquake problems to be solved.

A high priority should be assigned to establishing procedures, equipment and instrumentation and personnel for field testing. Such studies may include tests of structures scheduled for demolition, nondestructive evaluation of response, and performance of actual structural systems and components. The problems of scale and boundary conditions make laboratory studies of soil-structure interaction, lifelines, nonstructural elements and rehabilitation problematic, and require field studies of actual structures.

6.2 If funds were available for new testing facilities, what should be the relative allocation of resources for small, medium and large earthquake engineering test facilities nationwide?

There is an immediate need to upgrade and network existing laboratories and personnel, and to achieve full utilization of capabilities through sustainable research funding. Once this is done, then resources for new facilities should be considered based on an in-depth needs and allocation study.

6.3 How should a comprehensive national research program be administered or coordinated?

An administrative concept proposed at the 1984 EERI workshop is recommended. The concept consists of having one national center that is supported by regional laboratories and a larger number of "feeder" laboratories. The center may or may not have a laboratory, but would serve to coordinate and administer experimental research. The center would network the nation's research facilities and mobilize regional and feeder laboratories as needed to solve problems.

A high priority should be assigned to the development of a process for identification of problems and for the establishment of research agendas, priorities and facilities for earthquake engineering research in general, and experimental research in particular.

7. Projections of Future Research Capabilities and Results

Advancements in computer and servo-hydraulic technology have occurred faster than funding sources have increased over the last three decades. Innovative technological advancements in the coming years may make needed capabilities attainable in the future without a proportionate increase in cost.

7.1 What types of testing equipment for earthquake engineering research might exist in the next twenty, forty or sixty years?

The following is a list of equipment needs that are critical to advancing the state-of-the-art in earthquake engineering research.

- Large capacity, high performance servo-valves exceeding 20,000 gpm to permit application of large loads at realistic rates.
- High capacity special loading devices for protective systems (e.g. isolators and energy dissipators).
- Geotechnical centrifuges with high performance in-flight shakers.
- Inexpensive, wireless remote sensors for measurement of force, deformation and acceleration.
- Continuous structure monitoring (i.e. a "black box" similar to what is used today in aircraft).
- Field testing capabilities that permit the application of realistic loads and/or deformations both statically and dynamically to mid-rise buildings and multiple-span bridges.
- High performance control systems and actuators for effective force and pseudodynamic testing.
- Stronger and taller reaction walls.

The recent development of a 20,000 gpm servo valve will eliminate the demand for multiple valves. This will result in increasing performance and lower cost for future servo-hydraulic testing equipment. In the decades to come, the introduction of super conductivity should have a major impact on shaking table technology.

Future geotechnical centrifuges will be able to excite specimens in two directions, although further development of more refined and powerful single degree-of-freedom systems will continued to be pursued.

7.2 What new types of information on the seismic response of structures could be obtained with futuristic testing equipment?

Shaking tables of the future will be capable of exciting full-scale test structures with three-dimensional motions. These facilities will enable studies of much more realistic dynamic response than obtained with present equipment. For example, mechanisms of how shear walls in multistory buildings resist lateral forces can be observed as the wall simultaneously flexes under transverse inertial loads. Response of floors and roofs, and their connections to the shear walls can also be observed as the shear walls respond to multiaxial base accelerations. Because of the larger platform sizes, test structures can be constructed at a large scale which will permit full-scale specimens of low-rise buildings and taller specimens at moderately reduced scales.

With larger shaking tables, foundation effects can be studied by modeling a portion of the soil beneath a test structure. Dynamic response of pipelines encased in a container of soil could also be examined. Tests of larger size specimens will be possible in the future with larger centrifuges.

Larger structural engineering laboratories with a number of small shaking tables will be able to excite long bridge spans or pipeline assemblages with differential seismic input.

In addition to more accurate and more complete data for on site and material characterizations, measurement of real-time load path distributions will be possible as well as histories of deformation and pore pressure.

7.3 What differences will be required in the present laboratory infrastructure to accommodate testing equipment of the future?

Larger testing equipment will require larger laboratories. Laboratories should be as modular as possible to permit a wide variety of uses and accommodate a range of experiments from small to large scale. A set of independent, multiple shaking tables are one example of this modularity providing flexibility of use and increased efficiency.

Testing equipment should be mobile as much as possible so that it may also be used for field studies.

Coordination of research between laboratories will be enhanced with the increased sharing of facilities, data transfer via the Internet, remote testing capabilities, coordinated and standardized test protocols and exchange of technical staff.

8. Options for International Cooperation

Multinational cooperation has been intrinsic to the earthquake engineering research enterprise and to improved design practice for decades. Such cooperation has been a foundation of earthquake engineering research since the United States hosted the First World Conference on Earthquake Engineering in 1956. International coordination of research must not only continue, but be further strengthened and expanded.

8.1 What are the merits and limitations of having a multinational effort for earthquake engineering research?

The merits of a multinational effort for earthquake engineering research include:

- The exchange of personnel, data, perspectives, experience and knowledge.
- The access to large-scale or unique testing facilities unavailable in the U.S.
- The acceleration of the knowledge-creation process through global dissemination of research findings serving as feed stock for subsequent research.
- The understanding of differing seismic design practices among countries and working towards common codes in order to break down barriers to implementation and promote effective use.
- Learning lessons directly from destructive earthquakes in other countries and their implications to U.S. practice.
- The verification of research methodologies and test results.
- The building of long-term personal relationships between students, researchers, educators and specialists. The exchange and growth of intellectual resources cannot be over emphasized.

Although seismic design philosophies may differ between countries, experience has shown that all stakeholders benefit from multinational cooperation. Certain of the Japanese private sector construction research institutes are investing in the U.S. and other foreign earthquake engineering research centers and laboratories in order to maintain their edge in technology advances.

There are some limitations to realizing the full benefits of cooperation with other countries. These barriers include:

- Differing research agendas and emphases reflecting differences in building practices, professional expertise, societal ideologies, or pressing scientific needs.
- Coordination, communication and management challenges.
- Exchange of funding.
- Absence of a national model that effectively integrates and coordinates disparate research activities within the U.S.
- Weak domestic cooperation mechanisms.
- Cultural differences.
- A lack of a U.S. organization to set goals and priorities and stimulate actions.

The National Earthquake Loss Reduction Program (NEP) currently under study by the Clinton administration holds promise of fulfilling these goal-setting and coordination needs.

A major limitation to full cooperation with other countries is the inherent reluctance of the U.S. researchers to serve extended tenures at foreign research centers. Generally, there is a lack of incentive to do so, fostered by the widely held beliefs in this country that such as assignment would be a financial hardship, an interruption of professional development and detrimental to career growth. Foreign researchers coming to the U.S. usually do not hold such beliefs; assignments in the U.S. are highly sought after and prized.

8.2 What are the options to cooperate with other countries that have developed complementary earthquake engineering and testing programs and facilities?

A number of options for multinational cooperation suggest themselves based upon experience gained with existing models. Options include:

- Continue with the series of international workshops, world conferences, meetings, and individual contacts. International forums should be held on topics of narrow focus to increase their effectiveness.
- Expand the exchange of young researchers to and from the U.S.
- Reinforce existing cooperative programs and also use them as models to establish similar cooperative programs with other countries. These existing programs include as examples: the US-Japan Natural Resources Panel on Wind and Seismic Effects, the US-PRC program on Seismic Hazards and Earthquake Studies, the US-Russia program on Earthquake Disaster Reduction, the US-Japan Science and Technology Working Group and its subcommittee on Satellite Applications, and the International Decade for Natural Disaster Reduction.
- Consider programs in countries with frequent seismic activity as enhanced opportunities for field testing sites.
- Use the European Laboratory for Structural Assessment (under the Joint Research Center for the European Commission) as a model to mobilize cooperation within the U.S. as well as with other countries.
- Strengthen cooperative initiatives following destructive earthquakes wherever they occur.

Cooperation with other countries must be tailored to, and include two levels of cooperation: (1) basic research in the respective countries, and (2) proof testing at the bilateral level. Further, international forums are more efficient and cost effective when held to a narrow focus such as the U.S.-PRC-New Zealand-Japan workshop on building code issues.

History has shown that successful cooperation with other countries must include development of human resources along with other objectives. The exchange and growth of intellectual resources cannot be over emphasized.

8.3 How might a multinational effort for earthquake engineering research be mobilized?

Multinational cooperation has been at the foundation of earthquake engineering research for over forty years. Enhanced international initiatives can be mobilized through the creation of a national organization mechanism for strategic planning, coordinating, priority setting, and facilitating actions towards common national goals. The EERI, or the Clinton administration's pending National Earthquake Loss Reduction Program (NEP) have potential for serving this need.

Other suggested actions for mobilizing a revitalized multinational program include:

- Establish multiple levels of cooperation.

- Conduct national forums by a supporting organization to enable domestic cooperation and information exchange as a building block to enhanced cooperation with other countries.
- Establish a mechanism, and funding to support the use of the world's largest testing facilities such as the shake table in Tadotsu, Japan, or the reaction wall at the Building Research Institute in Tsukuba Japan.

The ultimate success of these initiatives hinges on three factors. Firstly, under-utilized research facilities in the U.S. must be better used to carry out the thoughtful research leading to understanding of concepts and subsequent proof testing. Secondly, existing cooperative research activities must be continuously assessed, improved, and expanded where appropriate; and not abandoned for the sake of pursuing new initiatives. Thirdly, the earthquake engineering research community, in concert with practicing design professionals, contractors and equipment suppliers, have critical roles to play in speaking out with a strong, unified voice on these issues and in enabling needed public and government policy reform to take place. Engineers and scientists, both as individuals and as a profession, must contribute actively to public debate and become more involved in providing leadership if the suggested multinational cooperative efforts for earthquake engineering research are to be achieved.

9. Operation and Maintenance of New National Facilities

9.1 What are the projected costs for construction, maintenance and operation of new earthquake engineering research and testing facilities in the United States?

The costs of operation and maintenance of experimental facilities is substantial. Many facilities are susceptible to reduced efficiency, rapid obsolescence or even interruption of service if adequate regular funding is not provided for maintenance and periodic upgrading. Experimental equipment is subject to heavy loading and susceptible to damage during tests; regular maintenance and replacement is required. Certain research equipment, such as instrumentation, electronic components and computers typically have very short service lives and suffer from rapid technical obsolesce. Budgeting for new research and testing facilities should therefore include realistic cost estimates for the maintenance and replacement of equipment. Failure to provide for these funds may results in reduced efficiency, the inability to conduct certain important types of tests, or even closure of facilities. As facilities become older, maintenance costs can become a major contributor to total operating expense, and host organizations may not be able to cover them.

Long-term sustained funding is needed at core facilities to train and retain staff capable of conducting state-of-the-art research and testing. A variety of highly trained engineers and skilled technicians are required in a number of specialties to formulate effective experimental test programs, to operate, adapt and maintain sophisticated test equipment and instrumentation, and to analyze test results. Analytically based research also requires skilled personnel to maintain computer equipment, networks and software. Currently research and testing activities are funded through relatively short term grants or contracts covering narrowly focused projects. By having a number of such projects, a research facility or laboratory can generate sufficient funds to operate, spreading the costs for these personnel out through the various projects at a reasonable rate. However, funding can vary greatly from year to year. If fewer projects are available, personnel with skills essential for continued operation may not be retained, or the operating cost assigned to each project increases, possibly to the point where the research is economically infeasible to conduct.

Funding should be provided at a level such that a minimum number of projects can be carried out at core institutions. This would enable facilities to budget for proper maintenance, training of personnel, and operation. When planning a new future facility, these operating and maintenance costs need to be anticipated when formulating budget estimates. These reoccurring costs are estimated as much as 10% of the initial capital cost of a new facility per year of operation.

Upgrading Existing Facilities. A high priority should be assigned to upgrading and expanding existing research and experimental facilities to provide them with new capabilities. The productivity in research and testing can be expanded greatly by building upon the capital investment and skilled personnel already associated with existing facilities.

Several new laboratories have been constructed in the U.S. during the past decade with government and private funds. These laboratories include several small to moderate scale reaction walls, and three small to medium size shaking table facilities. Furthermore, two of the largest shaking tables in the U.S. are currently undergoing extensive upgrades that greatly increase their capabilities. Several large geotechnical centrifuges have been built during the same time period. In spite of these increased resources, additional hydraulic power supplies, instrumentation and data acquisition systems, servo-hydraulic actuators, improved control systems, and shaking tables are needed to fully realize the capabilities of these and other similar existing facilities.

Technology has developed in the past decade to enable conventional equipment to more realistically subject specimens to seismic effects. Pseudodynamic tests allow for static reaction wall or field tests that stimulate, in slow motion, the dynamic response of the test specimen to earthquake ground motions, and even permit portions of specimens to be tested concurrently in different laboratories via a computer link. Digital and adaptive test control technology allow for highly complex and real time seismic loading on structures and subassemblies using hydraulic jacks rather than shaking tables. Systematic development and deployment of these capabilities at existing laboratories will significantly expand seismic test capabilities at relatively low cost.

New testing capabilities can be added using special purpose equipment installed with the infrastructure provided by existing laboratories. Such equipment may include high capacity or fast loading rate universal testing machines for evaluation of high performance materials, special fixtures for dynamic testing of full-scale energy dissipation or isolation devices, dynamic actuators for tests of active control and other systems, special purpose shaking tables for examination of nonstructural systems and contents, and so on. Addition of new reaction walls to existing reaction floors can allow for testing of moderate sized structures. Addition of increased hydraulic pumping capacity and distribution systems along with dynamic actuators can add dynamic testing capabilities to laboratories set up originally to conduct static experiments. Tremendous advances have been made in the past decade in instrumentation, sensors, control systems, computers and data acquisitions systems and their selective addition to the resources available at existing laboratories would substantially increase productivity and accuracy.

Field testing of actual structures is a particularly effective means of investigating inelastic behavior of full-scale structures and foundation systems. These tests have been hampered by data acquisition problems and limitations in loading capabilities. Such tests can be facilitated by more portable and robust data acquisition systems, remote sensing technologies and high capacity field loading systems now available.

Major New Testing Facilities. Major future facilities may include large, high-payload earthquake simulators or tall multi-directional reaction walls. These large-scale facilities would permit investigation of large structural components of building and bridge structures, complete structural systems, and foundation-structural systems. Such facilities need not be centralized, but could be cost-effectively constructed at or near other existing facilities where an infrastructure of personnel and ancillary equipment already exists.

Planning for these and alternative facilities should be based on experience with advanced testing facilities, and consider their economic benefits versus their cost relative to alternative methods of obtaining the same information. The construction cost of a new 100 ft by 100 ft shaking table is estimated to be on the order of $600 million. The feasibility of using available large-scale facilities in Japan and Europe should be carefully considered prior to constructing similar facilities in the US. Technology improvements and innovations may make lower cost facilities possible. Frequently cited examples were the use of multiple smaller tables in lieu of one large table, the use of pseudodynamic tests rather than dynamic tests, or field tests rather than laboratory tests.

None the less, large-scale experiments are still needed. These tests are a logical extension of the efforts to enhance the capabilities of existing facilities. They are needed to examine more complex systems, including interaction of frames, walls, floors, nonstructural partitions and cladding in buildings, infrastructure systems constructed of large elements, and foundation-structure systems to name a few application examples. Experience with the first round of upgrades may also indicate the need for special purpose facilities or equipment such as large, but low payload shaking tables for residential housing, or very high capacity apparatus for testing very large energy dissipation and isolation devices.

Projected Costs and Priorities. The highest priority should be assigned to modernizing and upgrading existing core research and testing facilities that contribute to a comprehensive national research program in earthquake engineering. Cost of this effort is estimated at $60 million spread over five to ten years. This level of funding is necessary to support an optimal short range research program , and is consistent with earlier recommendations by the National Research Council and EERI.

Along with this priority, funding should be assigned to implementing an earthquake engineering research program that will make full use of the upgraded and modernized facilities described above. Funding needs for operation and maintenance of these facilities, including the research and test program, are estimated to range between $40 and $50 million per year. These funds would permit research and integrated analyses and experimental laboratory or field testing in a variety of vital areas related to earthquake engineering.

As a second highest priority, large-scale testing facilities are needed for testing actual sized assemblages and devices, and structural and foundation systems with realistic seismic loading. The economic and technical feasibility of such facilities should be evaluated, considering the benefits of the test results and the costs of constructing and maintaining such facilities, and the practicality of using large-scale testing facilities in other countries. Special purpose facilities may be desirable and continued long-term upgrading of core experimental laboratories should be anticipated. The estimated costs of constructing these large-scale facilities is difficult to predict without a detailed feasibility study, however, a range of $180 to $300 million is considered reasonable. These expenditures should be phased to build upon the knowledge and experience gained from previous efforts. Such large-scale facilities would require operating budgets of approximately $100 million per year.

Development of a large-scale shaking table, similar in size to the one at Tadotsu Japan (49 feet by 49 feet), in the United States would require capital expenditures of slightly less than the $300 million cost paid by the Japanese. The annual maintenance cost of the Tadotsu facility is $10 million per year plus an additional $5 million per year for support of the technical staff. A total of twenty three tests have been run to date on the table with costs ranging from $4 to $40 million per test. Because of the large costs of operation and maintenance, the Japanese are contemplating termination of the facility in the next five years.

Capital costs for a very large shaking table (100 feet by 100 feet) are estimated at $500 million with operating and maintenance costs equal to approximately one third of this amount per year.

9.2 What are the options and recommendations for funding of construction and operation of new earthquake engineering and testing facilities.

Requirements for funding of large-scale facilities as addressed in the previous question are substantial, but small in proportion to the costs of earthquake-induced damage that occurs in the absence of research and testing made possible by these facilities. Similarly, the reduction in damage costs made possible through large-scale experimentation are two to three orders of magnitude larger than the cost of research. The improved seismic safety and restored confidence in the performance of the built environment will also contribute to the overall welfare of society.

Those that benefit directly from enhanced experimental research should contribute to its funding. The potential beneficiaries of earthquake research are numerous. A partial listing is included in Table 2. In some cases, the benefits (e.g. having a product certified as satisfying building code requirements) are direct, and easy to measure and assign to a group. In other cases (e.g. developing minimum design provisions for life safety protection), the benefits are more intangible and difficult to assign to a particular group.

Innovative concepts for collecting funds for earthquake engineering research and testing include the following.

- Construction companies could be mandated to contribute to a research fund in order to be eligible for federal and state construction contracts. This has been done in Japan with most construction companies electing to carry out their own research programs. In the U.S., construction companies are much smaller on average, a significant portion of these companies do not engage in government contracts, and company-based research programs would not be as effective as in Japan.
- A portion of the building permit fees could be designated to a research fund. Such a strategy is used to fund the California Strong Motion Instrumentation Program. Issues need to be resolved related to the collection of funds from local jurisdictions that collect building permits, and determination of appropriate fees depending on the type of structure and the seismic hazard. Collection of fees for non-building structures such as bridges and dams, and public buildings, would have to be done using alternative methods since building permits are not issued for their construction.
- Research requirements could be mandated to support changes in, or variances to building code provisions. This is done in Europe and Japan when new design details are proposed. However, the mandate would not provide an incentive to improve existing provisions of a building code, and generic type research for basic code improvement would not be supported.
- Suppliers of construction materials could be taxed. Establishing equitable rates could be problematic.
- Matching funds from research institutions be made required for all federally funded research grants.
- Charge a fee on earthquake insurance premiums to be applied towards research. This would help in assessing risk and providing a benefit (lower premiums or lower deductibles) for increasing seismic performance of buildings. However, earthquake insurance is not mandatory and many types of structures are not insured.
- States could collect funds through their local emergency management agencies. This could be a requirement for states to receive federal funds for emergency assistance.
- Research funds could be obtained from private individuals, foundations, foreign agencies and foreign companies. These sources are not likely to provide the magnitude and continuity of funding needed for an effective national program.
- The federal government needs to play a central role in funding research because it is a substantial beneficiary of the research results. The government can provide the focus and leadership for a comprehensive national earthquake loss reduction program.

Clearly, the question of funding options is a complex one, and one that extends well beyond the expertise of the earthquake engineering research community. Another group should be convened by the NEHRP federal agencies to consider possible options more in detail. Such a meeting should involve groups benefiting from or using research results along with public policy experts and government officials. Effective methods for aggregating funds collected from diverse groups and utilizing them effectively need to be examined further.

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Table 2
Partial Listing of Groups Benefiting from Earthquake Engineering Research

Type	Example
federal, state and local government	FEMA, NIST, DOT, DOD, DOE, HUD, GSA, VA, USGS
design standards enforcement officials or agencies	building officials, public utilities, Nuclear Regulatory Commission
public utilities	gas, power, water, sewer, liquid fuel, telecommunications
design professionals	structural, geotechnical and other engineers, architects
construction industry	contractors, construction managers, fabricators, craftspersons, trade unions
material suppliers	suppliers of steel, concrete, wood, masonry, fasteners, architectural elements
owners, insurance and financial entities	individuals, insurance companies, banks

9.3 What is the feasibility and advisability of developing a comprehensive earthquake engineering research and testing program within the scope of the Earthquake Hazards Reduction Act of 1977?

Development of a comprehensive earthquake engineering research and testing program within the scope of the Earthquake Hazards Reduction Act of 1977 (and as amended in subsequent years) is advisable. The reasons for this are manifold, including:

- More reliable and cost-effective codes for new construction, resulting in lower costs of earthquake damage, reduced time necessary for repair, increased construction productivity and greater public safety.
- More cost-effective and reliable methods for evaluating the seismic risk posed by existing buildings and for remediating their seismic vulnerabilities which could reduce the risk of injury and economic loss as a result of earthquakes.
- Improved methods for addressing policy issues related to insurance, risk mitigation, public assistance following earthquakes, and financing of public and private sector construction.
- Improved civil and military infrastructure systems capable of sustaining the economic and social welfare of the citizens of a region following an earthquake.
- Reduced risk associated with hazardous materials and facilities.
- Improved performance of critical or important facilities in the public and private sectors.
- Faster and more reliable introduction of innovative construction techniques and structural systems into design codes and practice.

- Improved synthesis and dissemination of knowledge and its application to practice.
- Improved education of students through university-based research and teaching through continuing education supported by research and testing results.
- Development of an expanded base of professionals, policy makers, building officials, researchers and others knowledgeable of seismic performance of the built environment, and of effective earthquake engineering techniques.

A comprehensive earthquake engineering research and testing program is feasible to implement. The U.S. has a small, but highly capable, base group of researchers, educators, design professionals, and regulators actively involved in the tasks for earthquake loss reduction. A comprehensive national program of research and testing could effectively and economically be built on these human resources as well as upon the foundation provided by the existing research infrastructure.

Experimental research is the cornerstone of any coordinated program for earthquake loss reduction. This view has repeatedly been expressed by previous groups, such as those convened by the National Research Council, EERI, and others.

A comprehensive research and testing program can be formulated consistent with the goals and scope of the National Earthquake Hazards Reduction Act of 1977.

A comprehensive research program should be developed as part of an open process that includes input from researchers, owners, design professionals, construction industry, and policy makers. By its very nature, the scope of the program should be broad involving numerous technical disciplines. Thus, issues related to soils and foundations supporting a structure, the structure itself, the contents of a structure should be considered as should the economic and social impacts of earthquake damage. Infrastructure systems consisting of several structures and of connecting elements (roads, electrical lines, pipelines, etc.) need to be considered. A comprehensive program for research and testing should also provide the balance between experiment and analysis, between laboratory and field testing, and between applied research and research for innovation.

Research and testing needs should be periodically updated. A careful analysis of the benefits of the research results should be made in comparison to the cost of obtaining these results. Research and testing is economical and can result in a procedure that can significantly reduce the impact and costs of future earthquakes.

A comprehensive research and testing program can be carried out through the existing NEHRP federal agencies. Operation of part of the program should be done through a coalition or consortium of research organizations. Precedent for this type of operation exists in other fields and is being utilized by the European Community.

Specific methods for formulating, organizing, funding and operating this program should be promptly explored.

10. Concluding Remarks

This assessment has stressed the importance of experimental research in reducing earthquake losses, and the need for a more aggressive national research plan. The state of present research and testing capabilities has not developed at a pace consistent with the needs for an improved understanding and awareness of earthquake hazards. Upgrading of existing facilities and development of new regional centers is needed along with increased funding for experimental research. Alternate sources of funding must be sought to meet the needs, and multinational cooperation must be relied on for the sharing of data, research results, equipment and personnel.

The following seven specific recommendations are given.

1. A comprehensive plan must be developed for experimental earthquake engineering research to effectively utilize existing laboratories and personnel, to upgrade facilities and equipment as needed, and to integrate new, innovative testing approaches into the research infrastructure in a systematic manner.
2. Experimental research programs must be pursued at an accelerated rate to advance the state of the art in seismic engineering and construction practices, and as a result, enhance public safety and reduce economic losses in future earthquakes.
3. As the highest priority, existing laboratories must be upgraded and modernized with new testing equipment.
4. As a second high priority, a series of new, moderately-sized regional centers must be created with unique, and complementary capabilities.
5. A detailed feasibility study should be undertaken to estimate benefit-to-cost ratios associated with development, maintenance and operation of a single, national test facility.
6. Future funding of earthquake engineering research must be sought through alternate, innovative sources.
7. Existing cooperative research programs with other countries should be continued, and new programs should be established where the sharing of testing facilities, and the exchange of data and research results is mutually advantageous.

Commentaries on each of these recommendations can be found in the Executive Summary.

This assessment was exploratory in nature. Detailed feasibility studies should follow to make more accurate estimates of needed research facilities, costs of upgrading existing laboratories, and costs of developing and operating new laboratories. The assessment findings represent the opinions of the participants at a two-day workshop, and do not necessarily reflect those of the sponsors.

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APPENDIX A: COMMISSIONED PAPERS

1. *A Historical Perspective on Previous Assessments of Experimental Facilities*
Robert D. Hanson, University of Michigan and FEMA, Pasadena, CA

2. *Worldwide Survey of Earthquake Engineering Testing Facilities*
Freider Seible, University of California at San Diego
and Benson Shing, University of Colorado at Boulder

3. *A Practitioner's View on Research for Seismic Design of Buildings*
Eric Elsesser, Forell/Elsesser Engineers, Inc., San Francisco, CA

4. *A Practitioner's Point View on Research for Seismic Design of Bridges*
James E. Roberts, California Department of Transportation, Sacramento, CA

5. *Experimental Research Toward Abatement of the Seismic Risk: Why, What and How?*
Mete A. Sozen, Purdue University

6. *Problems in Geotechnical Engineering that Demand Experimental Research*
William F. Marcuson III, R.H. Ledbetter, R.A. Green, R.S. Steedman, A.G. Franklin
and M.E. Hynes, Waterways Experiment Station, Vicksburg, MS

7. *Problems in Lifeline Earthquake Engineering that Demand Experimental Test Facilities*
Douglas G. Honegger and Ronald T. Eguchi, EQE International. Irvine, CA

8. *Large-Scale Testing Facilities for Earthquake Engineering in Japan*
Makoto Watabe, Shimizu Construction, Tokyo, Japan

9. *A Futuristic View of Structural Experimental Facilities*
Allen J. Clark, MTS Corporation, Minneapolis, MN.

10. *A Futuristic View of Geotechnical Experimental Facilities*
Jacques Perdriat, Acutronic Corporation, France
and Andrew Schofield, University of Cambridge, England

11. *Lessons Learned from Mobilizing European Cooperation in the Construction and Operation of the ELSA Laboratory*
G. Michele Calvi, University of Pavia; Jean Donea, Paoio Negro, and
Guido Verzaletti, ELSA Laboratory for European Community, Ispra, Italy

12. *Options for Structure, Operation and Funding to Improve National Experimental Testing Capability*
William J. Hall, University of Illinois at Urbana-Champaign

APPENDIX B: WORKSHOP INFORMATION

Appendix B.1 Workshop Program

EERI Workshop on
Assessment of Earthquake Engineering Research and Test Facilities

July 31-August 1, 1995
Parc 55 Hotel
San Francisco, CA

Sunday, July 30

6:30-8:00pm **Reception:** Atrium, 4th Floor

Monday, July 31

8:00am **Registration:** outside of Parc III Room, 4th Floor; *coffee and rolls will be served*

General Session: Parc III Room

8:30am *Welcome and Introductions*: Daniel Abrams, University of Illinois at Urbana-Champaign
Purpose of Workshop: James Beavers, MS Technology, Inc., Oak Ridge, TN

9:00am *A Historical Perspective on Previous Assessments of Experimental Facilities*
Robert D. Hanson, University of Michigan and FEMA, Pasadena, CA

9:25am *Worldwide Survey of Earthquake Engineering Testing Facilities*
Freider Seible, University of California at San Diego
and Benson Shing, University of Colorado at Boulder

9:45am *A Practitioner's View on Research for Seismic Design of Buildings*
Eric Elsesser, Forell/Elsesser Engineers, Inc., San Francisco, CA

10:15am *A Practitioner's Point View on Research for Seismic Design of Bridges*
James E. Roberts, California Department of Transportation, Sacramento, CA

10:45am Break

11:00am *Experimental Research Toward Abatement of the Seismic Risk: Why, What and How?*
Mete A. Sozen, Purdue University

11:30am *Problems in Geotechnical Engineering that Demand Experimental Research*
William F. Marcuson III, R.H. Ledbetter, R.A. Green, R.S. Steedman, A.G. Franklin
and M.E. Hynes,Waterways Experiment Station, Vicksburg, MS

12:00am *Problems in Lifeline Earthquake Engineering that Demand Experimental Test Facilities*
Douglas G. Honegger and Ronald T. Eguchi, EQE International. Irvine, CA

12:30pm **Lunch:** Parc II Room

2:00pm **Discussion Group A:** Raphael Room
Evaluation of Existing Capabilities

Discussion Group B: Rubens Room
The Need for New Earthquake Engineering Test Facilities

Discussion Group C: Dante Room
Development of a Comprehensive National Research Program

4:30pm **General Session:** Parc III Room
Summarize Discussion Groups A, B and C

5:30pm Close for Day

5:30-7:00pm **Reception:** Atrium, 4th Floor

Tuesday, August 1

	General Session: Parc III Room, 4th Floor
8:30am	*Large-Scale Testing Facilities for Earthquake Engineering in Japan* Makoto Watabe, Shimizu Construction, Tokyo, Japan
9:00am	*A Futuristic View of Structural Experimental Facilities* Allen J. Clark, MTS Corporation, Minneapolis, MN.
9:15am	*A Futuristic View of Geotechnical Experimental Facilities* Jacques Perdriat, Acutronic Corporation, France and Andrew Schofield, University of Cambridge, England
9:30am	*Lessons Learned from Mobilizing European Cooperation in the Construction and Operation of the ELSA Laboratory* G. Michele Calvi, University of Pavia; Jean Donea, Paolo Negro, and Guido Verzaletti, ELSA Laboratory for European Community, Ispra, Italy
10:00am	*Options for Structure, Operation and Funding to Improve National Experimental Testing Capability* William J. Hall, University of Illinois at Urbana-Champaign
10:30am	Break
10:45am	**Discussion Group D:** Raphael Room Projections of Future Research Capabilities and Results
	Discussion Group E: Rubens Room Options for International Cooperation
	Discussion Group F: Dante Room Operation and Maintenance of New National Facilities
1:00pm	**Lunch:** Parc II Room
2:00pm	**General Session:** Parc III Room Summarize Discussion Groups D, E and F Formulate Workshop Resolutions
4:00pm	Adjourn

Appendix B.2 Discussion Group Attendance

Discussion Group A:
Evaluation of Existing Facilities

Tom Anderson
Greg Brandow, moderator
Riley Chung
Allen Clark
Gene Corley
Greg Deirlein
Bruce Douglas
Ahmad Durrani
Ahmed Elgamal
Michael Englehardt
Barry Goodno
Suzzette Jackson
Bruce Kutter
Le Wu Lu
Paolo Negro
Jacques Perdriat
James Radziminski
Frieder Seible
Benson Shing, recorder
Drexel Smith
Chris Thewalt

Discussion Group B:
Need for Earthquake Engineering Research and Test Facilities

William Anderson
Ian Buckle
Paul Clark
A.J. Eggenberger, moderator
Phil Gould
John Hall
James Harris
Doug Honegger
Roberto Leon
H.S. Lew
James Malley
Jack Moehle
Armand Onesto
Clarkson Pinkham
James Roberts
Enrico Spacone
John Stanton, recorder
Richard Stroud
Robert Tauscher
Makoto Watabe

Discussion Group C:
Development of a Comprehensive National Research Program

Mihran Agbabian
James Anderson, recorder
Vitelmo Bertero
Michele Calvi
Sigmund Freeman
William Hall
Robert Hanson
Jack Hayes
James Jirsa, moderator
Helmut Krawinkler
S.C. Liu
Stephen Mahin
William Marcuson
Frank McClure
Gerald Pardoen
Joseph Penzien
Chris Rojahn
Erdal Safak
Mete Sozen
Richard Wright
Art Zeizel

Discussion Group D:
Projections of Future Research Capabilities and Results

Greg Brandow
Ian Buckle, moderator
Riley Chung
Greg Deirlein
Bruce Douglas
Michael Englehardt, recorder
Sigmund Freeman
Barry Goodno
John Hall
Helmut Krawinkler
Bruce Kutter
James Malley
Armand Onesto
Clarkson Pinkham
Drexel Smith
Mete Sozen
John Stanton
Richard Stroud
Robert Tauscher
Chris Thewalt

Discussion Group E:
Options for International Cooperation

William Anderson
Tom Anderson, moderator
Vitelmo Bertero
Michele Calvi
Ahmad Durrani, recorder
Doug Honegger
Ahmed Elgamal
Enrico Spacone
Phil Gould
James Jirsa
Roberto Leon
H.S. Lew
Le Wu Lu
Paolo Negro
Jacques Perdriat
Igor Popov
James Radziminski
Erdal Safak
Frieder Seible
Benson Shing
Makoto Watabe

Discussion Group F:
Operation and Maintenance of New National Facilities

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James Anderson
Klaus Cappel
Allen Clark
Gene Corley
A.J. Eggenberger
William Hall
Robert Hanson
James Harris, recorder
Jack Hayes
Suzzette Jackson
S.C. Liu
Stephen Mahin, moderator
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Frank McClure
Jack Moehle
Gerald Pardoen
Joseph Penzien
James Roberts
Chris Rojahn
Richard Wright
Art Zeizel

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Mr. BAKER. Thank you, Dr. Abrams. Dr. Komor, you mentioned that some of your recommendations might be controversial.

Could you explain that a little?

Mr. KOMOR. Yes. All the options that relate to insurance and disaster systems are quite controversial because of the huge amounts of money involved and the potential for financial impacts on the insurance industry.

There's also a secondary issue that is controversial in a different sense, which relates to looking at the appropriate Federal role in mitigation. Is it the Federal Government's role or responsibility to influence individual behavior or to regulate individual behavior? That is, also, of course, quite controversial as well.

Mr. BAKER. And, the third is the building standards in this era of unfunded mandates. Can we really tell local governments and state governments they ought to be doing all this, huh?

Mr. KOMOR. Yes.

Mr. BAKER. You also said that the program lacks focus. Is that because our congressional mandate is unclear; or, is it because there are four agencies all going the wrong way?

Mr. KOMOR. I think both factors. Certainly, the legislation, NEHRP, itself does lay out some broad goals—interactions, but they are not—I certainly wouldn't characterize them as very specific direction.

And, one option for the Congress is to take the initiative to set very specific goals. I think what would be preferable, in my mind, is to ask the lead agency, FEMA, to set some very specific goals, goals that could be measured.

For example, one goal we offer, not because this is a good goal but to provide an example, would be to define some percent of the building stock in some future year to incorporate known technologies as captured in current codes. It would be an example of a very specific goal.

This would not only give the program more direction but would provide a better way to measure the success of the program.

Mr. BAKER. Well, I want to compliment you on your report. It's excellent.

Mr. KOMOR. Thank you.

Mr. BAKER. It's well done. And, it has brought together a lot of resources that are good for Congress to look at.

Dr. Abrams, you mentioned spending $180 million to $300 million on testing facilities. In the laboratories, we are now simulating automobile crashes and impacts of bombs by using computers.

Do you feel that there is anyway we could attempt to simulate the effect of an earthquake or a shake without actually building a laboratory large enough to shake buildings?

Mr. ABRAMS. Well, we do have computer models that have been developed for doing that. But, we need to have tests to confirm those results.

Also, by doing tests, you can see observations in the test results that stimulate to create new computer models. So, it just can't be guessed at. It needs to be observed with a test specimen.

Mr. BAKER. Since we don't know where the next one is going to be, how would we observe it even if we had the equipment?

Mr. ABRAMS. Well, you would do it after the fact by looking at the damage.

Mr. BAKER. At the building?

Mr. ABRAMS. And, the buildings cannot be instrumented. All buildings can't be instrumented. Whereas, in the laboratory environment, they can.

Mr. BAKER. If I were to ask you to focus your spending, what would you do first?

Mr. ABRAMS. As I mentioned in the report, to upgrade the existing facilities in the country.

Mr. BAKER. Just upgrade the existing facilities?

Mr. ABRAMS. Yes. That's our highest priority.

Mr. BAKER. And, what was your ball park figure for that?

Mr. ABRAMS. $60 million over 5 to 10 years.

Mr. BAKER. Okay. Mr. Geren.

Mr. GEREN. Thank you, Mr. Chairman. I thank the witnesses for their testimony.

That $60 million—just to follow up on your last answer—that's in addition to the annual $40 million a year?

Mr. ABRAMS. That's the capital investment cost. The operating cost was estimated at $40 million to $50 million once those facilities would be operational.

Mr. GEREN. In comparing the information you get from the computer modeling with the actual testing, would it be analogous to the aerospace industry where you've got computer modeling on wings but that has not done away with the need for air tunnels that actually—

Mr. ABRAMS. Exactly

Mr. GEREN. —show how that would behave and all?

Mr. ABRAMS. Right.

Mr. GEREN. You talked about international cooperation and the drawbacks or limits to that. It would seem to me that if there is any area that would be right for extensive international participation, it would be this sort of testing.

What would be some drawbacks to international collaboration and then push that much harder than we have currently pushed it?

Mr. ABRAMS. Well, we do have cooperative programs with other countries where we do mutual testing. But, the construction methods in the various countries differ.

For example, I conducted a cooperative program with Italy on masonry structures. And, their masonry practices are different. Their materials or craftsmanship are different.

It's good to see what's going on abroad, but you can't rely on that exclusively.

Mr. GEREN. Are there other countries where we do have sufficiently common practices where there would be a good deal of overlap?

I mean, does Japan fall in that category with all of their new construction?

Mr. ABRAMS. Well, we've had a number of cooperative programs with Japan on concrete buildings and steel buildings and masonry buildings and precast concrete buildings and now composite steel concrete buildings. And, there has been quite a bit to learn from that.

But, their building codes are different in each country. We can't rely exclusively on the international part. It's something we can learn quite a bit from but not exclusively.

Also, much of the research done in the United States is done at universities. And, it's difficult to export our graduate students abroad and expect them to get degrees in the U.S.

It's the nature of the beast. We must keep them at home.

Mr. GEREN. It just seems, when you consider your recommendation of $60 million and you consider the tens and hundreds of billions that are lost internationally, you are talking about a drop in the bucket there.

Mr. ABRAMS. Oh, it's a fraction of a percent.

Mr. GEREN. If you could bring together all the interested parties, even if you had to, you know, triple it or quadruple it, it just seems—

Mr. ABRAMS. Oh, 5,000 times. The losses due to Loma Prieta and Northridge were the upper end of—it was about $50 billion. We are talking about $60 million. So, there is a factor of a thousand right there.

Mr. GEREN. I just wonder if we have done everything we can to maximize the opportunities for international collaboration.

Mr. ABRAMS. Well, we list a few in our report on where we can go from here. We can perhaps improve on what we have. But, it's just not the only way to go.

Mr. GEREN. Have you seen in other countries—I guess, could you review the state of the private sector participation? You made some very interesting suggestions for fees or taxes to go to the private sector to help fund this kind of research.

Are there certain states that have already done anything along these lines or other countries that have looked to the private sector and come up with a mechanism to fund this sort of research?

Mr. ABRAMS. Not that I know of. California, I believe, has had some with insurance industries.

But, that's a little bit beyond my realm. I'm sorry. Certainly not in Illinois.

Mr. GEREN. Well, in your testimony, I thought that was the states, in many ways, have the best of both worlds now. They can resist the unfunded mandates, as the chairman was referring to, but then the Federal Government is going to be there and pay the bill.

You know, it seems to me they shouldn't be able to have it both ways. And, yet, the politics are such that when a disaster happens, regardless of what the behavior was that preceded it, the Federal Government is going to pay the bill.

And, it seems to me this is a case for, at least, some limitations on the unfunded mandate issue, knowing full well that if the disaster comes we are not going to be able to say no.

Mr. ABRAMS. That's right.

Mr. GEREN. That's the current problem. I can't think of—I will tell you, I've only been here—this is my fourth term, but how many bills I've voted for to send money to California. It's almost an annual occurrence.

Mr. BAKER. And, we appreciate each one of those votes.

[Laughter.]

Mr. GEREN. It's like the fall harvest.

Mr. BAKER. We tried to give it all back in the super duper super collider, but we failed.

Mr. GEREN. That's right. And, failed miserably, I might say.

[Laughter.]

Mr. GEREN. I have a couple of questions for Dr. Komor, but let me hold off on those until my colleagues have an opportunity to ask some questions.

Thank you, Mr. Chairman.

Mr. BAKER. Thank you, Mr. Geren. And, Mr. Bartlett. And, we are very happy to be joined by Dr. Ehlers also, our second scientist.

Mr. BARTLETT. Thank you very much. In building for earthquakes, it's fairly obvious that there are some things that one can do that will not increase costs. It's simply a selection of appropriate materials and techniques.

For instance, frame is obviously more resistant to earthquakes than typical unreinforced masonry construction. But, when you go beyond that, when you are now requiring building techniques that do increase costs, have we done any cost benefit analysis to see when we reach the point of diminishing returns, when it would just be cheaper to buy the insurance, since not every building in the country is going to be subject to earthquakes and some of them may never be and requiring exorbitant increases in costs to protect buildings against earthquakes?

At some point, it would be rational to just pay the insurance and share the risk rather than design every building in the country so that it would ride out a Richter scale 8.0 earthquake. Has that kind of analysis been done?

And, if not—obviously, you must make some assumptions. But, I think from history we can make those kinds of assumptions.

Has that kind of analysis been done so that we can rationally approach these building codes and the increased costs that are imposed on businesses and families?

Mr. KOMOR. I will take a cut at that question. I think the short answer is no.

The current codes do have different standards or levels. For example, you have to do more in California than in Texas, because the risk is higher.

However, due in part to the uncertainty over future earthquake occurrence, it's hard to do that cost benefits, because we don't know what's going to hit us and when it's going to hit us. So, it's difficult to determine the optimum level.

The codes try to do that through a consensus process, basically a lot of smart people getting together and deciding what is an appropriate level of safety. But, I wouldn't call it an optimizing process.

Mr. BARTLETT. But, unless you've done a systematic analysis, you are very likely, in terms of a cost benefit analysis—since we don't have all the money in the world, although this Congress has in the past behaved as if it might—since you don't have all the money in the world you really need, it seems to me, a cost benefit analysis to know when you are reaching the point of diminishing returns so that it now no longer becomes productive to build in more earthquake proofness in buildings; but it now becomes productive simply to share the risk by paying for insurance to protect you in the event of an earthquake.

It seems to me that a rational society would need to decide. Obviously, you've got to make some judgments—earthquakes are going to hit more often in California than they do in Nebraska, for instance. And, you will obviously want to have more protection in California, more building code requirements and/or more insurance.

But, it seems to me that this is something that—this is a role that the Federal Government could play in providing the research capability for this kind of analysis, because this now can be shared by all of the states.

Mr. KOMOR. I agree. I will just point out that we do know the costs reasonably well, but the benefits are very uncertain because the timing of the future earthquakes and the incremental reduction in damage that would occur from the strengthening is somewhat uncertain as well.

Mr. BARTLETT. Okay. I thank you very much. Thank you for your testimony.

Mr. BAKER. Dr. Ehlers.

Mr. EHLERS. Thank you, Mr. Chairman. First, Dr. Komor, I simply want to comment that I appreciate your report. I appreciate the service that you and others at OTA have provided.

I was heavily involved in the fight to preserve it in some fashion or other. And, I deeply regret that it no longer exists.

And, please pass my appreciation on to your former colleagues as well.

Mr. KOMOR. I will do that. Thank you for the kind words.

Mr. EHLERS. Yes. We certainly appreciate everything you've done. And, this report is an example of the fine work you do.

Dr. Abrams, just a question. We had someone testify last year that in the Northridge earthquake an item of great concern in examining the damage said that apparently all the standards that have been established in laboratories for weld strength on steel structures are probably wrong, because those are welds made in the laboratory under ideal conditions and when you have a worker hanging upside down on the eighteenth floor making welds you don't get quite the same quality of weld.

I would just like your comments on that. Is that, in fact, in your opinion, a valid concern?

Should the codes be revised to take account of that and to require a greater weld strength, assuming on the average that the typical weld is not going to meet the ideal specifications?

Mr. ABRAMS. Yes. There is a major program underway, a research program, which is called the—I guess there is a book on it here, funded by FEMA—called the "SAC Activity." It's a consortium of the Structural Engineers Association of California, the Applied Technology Council and the California Universities for Earthquake Engineering Research.

They have gotten some support from FEMA. And, I guess the interim guidelines have been published.

There is a significant amount of money provided for the research to improve building codes for steel structures. And, there have been weld failures in the laboratory, too.

As a matter of fact, there were weld failures observed at the University of Texas before Northridge of a similar sort indicating this problem. But, that was the only source of that information.

There wasn't enough supporting information to change the codes before the earthquake. Had perhaps the funding levels for research been higher we could have identified that problem beforehand, which is again an underscoring of my previous comments on being able to test large scale replicas of our buildings to identify these problems beforehand.

Mr. EHLERS. All right. Perhaps if Governor Weld of Massachusetts becomes President Weld at some time in the future we would have concern for good welds at the very highest level of this nation.

[Laughter.]

Mr. EHLERS. One other question. At yet another hearing on this topic, a dispute emerged.

There appeared to be a dispute between the State of California representatives, or at least those from Southern California, and the USGS, I believe, about the maps that are used as a basis for zoning requirements on building codes.

Are you familiar with this at all or not?

Mr. ABRAMS. I do know that the mapping issue has been under study with the Building Seismic Safety Council and their new provisions update processes incorporating new maps for the next—

Mr. EHLERS. But, you are not aware of the dispute?

Mr. ABRAMS. But, that's seismology and geophysics.

Mr. EHLERS. All right, fine. I just wanted to see if you had heard of that.

I tried to cut through that. And, the staff of the Committee was kind enough to do some research on this.

And, it seems to me the USGS was probably doing the right thing.

Mr. ABRAMS. It's a very political process of assigning seismic zones to various counties.

Mr. EHLERS. Right, probably particularly in California.

Mr. ABRAMS. Right.

Mr. EHLERS. Thank you very much, Mr. Chairman. I yield back the remainder of my time.

Mr. BAKER. You are very welcome. And, Panel 2 has a representative from the USGS. So, you will be able to ask that again.

Peter, back to you. Have you got a thought?

Mr. GEREN. Go ahead.

Mr. BAKER. Mr. Luther, we are very happy you are here.

Mr. LUTHER. Thank you.

Mr. BAKER. Do you have questions of this panel?

Mr. LUTHER. Just a question. I think it would be helpful—thank you, incidentally, for the hearing. And, I certainly want to thank the panelists.

I would be interested in any comments that you might have on the bill known as the Natural Disaster Protection and Insurance Act of 1995. It's a bill that surfaced and obviously the intention is to inject mitigation and insurance considerations into this entire debate and discussion.

And, I would just be—as long as you are here on this subject, I would be interested in your thoughts on that.

Mr. KOMOR. I'm somewhat familiar with the bill. The only comment that I would be comfortable making is that the mitigation component is a very important component.

And, I agree with the decision to make sure that mitigation is included in the legislation and that there are sufficient incentives or other ways to ensure that mitigation money is spent up front to avoid the problem of moral hazard.

That's a term that comes from the insurance field. That means basically if you don't think you are going to have to pay for the damage, you tend not to be as careful as you would otherwise be.

So, I'm extremely pleased to see that the bill does have a strong mitigation component.

Mr. ABRAMS. All I know about it is what I saw on the Internet the other night, something that is including the other hazards in with earthquakes as well, in which case it would be a broader focused bill than the NEHRP. I really can't comment.

Mr. LUTHER. I appreciate that. I'm hearing increasing discussion of it.

And, I know there is considerable interest on the part of many, many people. And, certainly I've been contacted by constituents as well.

And, I just thought that I would raise the issue and see if you had any particular input that you could share with us. Thank you.

Mr. BAKER. That measure allows for a pooling of insurance resources so that you are not left naked, so to speak, when it hits in your community alone. And, it does, I think, include other disasters.

But, that and raising the standards will help insurance companies stay in business, because we lost several insurance companies in the Southern California quake who were stable until that time. But, when you lost 4,000 insureds in one day, you are not—there is no way you can build an actuarial table that will mitigate that.

So, by allowing all the companies nationwide to avoid the antitrust legislation and to pool their resources, then we can keep these companies in business. The net result, by the way, Mr. Luther, was nobody will write in California right now.

So, you can't get insurance. Nobody wants the additional risk. So, this will be a very important piece of legislation when it comes.

Peter has a further question. Mr. Geren.

Mr. GEREN. Thank you, Mr. Chairman. Dr. Komor, I would like you to talk a little about FEMA.

Your report says that FEMA is the best candidate to be the lead agency in NEHRP. And, can you explain how you reached that conclusion and also highlight FEMA's efforts so far to manage the program and the changes that they have brought about in recent years?

Mr. KOMOR. Yes. That is a controversial issue. That is the issue of who should be the lead agency.

In our view, of the four NEHRP agencies, FEMA is the most appropriate lead agency because what is emerging as the key challenge for NEHRP is implementation. It's getting these technologies and practices in place.

And, FEMA has a management rather than a research mission and is, therefore, the best of the four agencies to manage it. In my view, if lead agency status is given to a research oriented agency, such as the National Science Foundation, NEHRP will become increasingly a research program. And, in my view, that doesn't meet well with the current challenge it faces to actually implement.

It is—also, in our view, FEMA has certainly been criticized since NEHRP's inception for failure to lead in an aggressive way. As I noted in my testimony, one possible solution to that is for Congress to direct FEMA to come up with very explicit targeted and measurable goals for NEHRP and to provide oversight and for the other agencies to make sure they all cooperate to see that these goals are defined and met.

Mr. GEREN. Well, FEMA only comes to the public's attention at the time of a disaster. And, of course, nobody who is at the disaster is ever satisfied with the handling of the disaster.

They are just confronted with almost impossible logistical tasks. I only say that, because I don't want to stand here and try to offer my own personal judgment of FEMA. But, I will say that we often hear criticism of FEMA's management of disasters in their aftermath.

When you choose FEMA as the best candidate for the lead agency, are you only choosing among the four?

Are you satisfied that FEMA has the capabilities within that organization to handle this program effectively; or, are you only choosing them because you only have four choices?

Do you think that it's something we should consider looking outside the capabilities of the four?

Mr. KOMOR. In my view, of the—

Mr. GEREN. We know how you feel of the four.

Mr. KOMOR. Yeah, okay. I've made it clear of the four.

I think FEMA, under its new director, has certainly publicly stated a much stronger interest in orientation towards mitigation. In my personal view, FEMA, with appropriate and perhaps frequent oversight from this Committee, if given a clear mission of establishing clear and measurable goals, could do the job.

Mr. GEREN. Do you think that FEMA is strong in being proactive rather than reactive?

Again, we only see FEMA in action—I'm speaking from the general public's point of view—in reacting to disasters. Do you think they have experience that would demonstrate that they are good at being proactive and in coming up with mitigation plans and actually working with communities, having the political skills, the skills that would have to be brought to bear in order to pull off something like this?

I mean, coming up with a good mitigation plan, there's a whole lot more to that than just knowing how to do it. It would be a very complicated political task.

It would involve probably reaching out to get the private sector to participate. It's quite a chore for all the reasons we've discussed.

And, I just would like your opinion on whether or not you think that those skills currently reside in FEMA or if what you see in

FEMA is largely an agency that is best at just reacting and trying to mitigate a disaster that has occurred.

Mr. KOMOR. I think, in the past, FEMA has been almost entirely a reactive agency. That has been their job, to react to disasters.

However, in the last few years, they have tried to build a proactive capability. I don't think they have demonstrated the ability to do that in the past, but again of the four agencies they seem the most likely to be able to get that done in the future.

Mr. GEREN. Okay. It's hard to do these proactive initiatives, whether it's trying to get people not to build in flood prone areas or trying to get communities to do these sort of mitigation measures.

And, I just wonder if we don't need to focus on—instead of giving them a task that's an impossible task for them, if we are truly interested in bringing about these mitigation efforts, if we don't need to give them additional tools or perhaps even look outside of an organization whose job really is to try to help people deal with an awful situation after it's there.

Thanks, Mr. Chairman.

Mr. BAKER. Thank you, Mr. Geren. One last question. In 25 words or less, are California building standards adequate?

Mr. ABRAMS. They are improving.

Mr. BAKER. They are improving? Are they in all areas where a quake might occur?

Mr. ABRAMS. I'm sorry, are the standards in—

Mr. BAKER. Yes, standards implemented by building codes. Are the building codes sufficient to do the job in California?

Mr. ABRAMS. For new construction?

Mr. BAKER. Yes.

Mr. ABRAMS. I would say they are fairly good. For existing buildings, we are working on it.

There are new standards being created, as we speak, through the Building Seismic Safety Council for rehabilitation of existing buildings.

Mr. KOMOR. I would just add the caveat that they are likely sufficient if enforced and applied correctly, which is not always the case.

Mr. BAKER. Okay. Thank you very much, both of you, for being here today.

We would like to introduce Panel 2 without any hesitation so that we don't lose our audience up here. Congress has been accused of having a very short attention span, so we want to make sure that we don't lose any of the great witnesses we have here today.

Mr. Richard Moore is Associate Director for Mitigation, the Federal Emergency Management Agency. And, he will be able to directly answer Mr. Geren's last three questions.

Dr. Richard Wright, Director, Building and Fire Research Laboratory, National Institute of Standards and Technology; Dr. Joseph Bordogna, Assistant Director for Engineering, National Science Foundation; and, Dr. Robert Hamilton, Coordinator for Geologic Hazards Program Office, United States Geological Survey.

Welcome. And, if for no other reason, we will just start with Mr. Moore and work across. And, thank you for being here.

STATEMENT OF RICHARD T. MOORE, ASSOCIATE DIRECTOR FOR MITIGATION, FEDERAL EMERGENCY MANAGEMENT AGENCY

Mr. MOORE. Thank you, Mr. Chairman, members of the Subcommittee. I am pleased to appear and discuss the role of the Federal Emergency Management Agency in your program.

In the last several years, we have been beset with an unprecedented series of natural catastrophes, the costs of which would be unthinkable only a decade ago. The litany of these events is well known to all of us from Hurricanes Hugo, Andrew, Iniki and, most recently, Marilyn and Opal, to the midwest floods and the Loma Prieta and Northridge earthquakes.

Of the natural hazards just listed, earthquakes, in spite of the advances made by the NEHRP agencies, present us with perhaps the greatest challenges for several reasons. First, we are still learning when it comes to understanding completely the forces that generate earthquakes and the possible location and timing of their occurrence.

Second, because of their comparative infrequency, it's difficult to raise and sustain a level of public concern necessary to carry hazard reduction programs forward. And, third, we are still in a developmental stage when it comes to designing and building earthquake resistant structures and to rehabilitating older buildings and infrastructure.

This is not to deny the impressive gains that have been made since the passage of the Earthquake Hazards Reduction Act of 1977 but to acknowledge the magnitude and complexity of the problems with which we continue to grapple.

FEMA has a dual set of responsibilities, as has already been mentioned, under NEHRP. The first set is related to the role of lead agency for the program. In this regard, we are responsible for presenting a consolidated budget to the Office of Management and Budget, for overall program planning, for biennial reports to the Congress and for promoting the implementation of the earthquake hazards reduction measures by all levels of government, the standards and codes organizations and the construction sectors.

The second set of responsibilities involves implementing hazard reduction activities, including providing grants and technical assistance to states and local governments, earthquake education and public awareness, development and dissemination of information on seismic resistant building standards and practices, earthquake disaster response planning and integrating earthquake hazards reduction with other natural and technological hazards reduction techniques.

As I am sure you are aware, Mr. Chairman, the Administration received a letter in November of 1993 from several members, raising a number of concerns about NEHRP, at least two of which were related to the lead agency functions, the lack of an overall strategic plan and insufficient coordination among the agencies to shape a unified and coherent program. The Administration has just completed a study of the program and is instituting changes to include more agencies and to designate a program officer in FEMA to be responsible for overall program management.

FEMA continues to share the vision of the Congress for NEHRP, a program that is more closely coordinated in the context of a clearly defined set of objectives, and pledges to exert every effort in the context of the Administration's decisions to make that vision a reality.

With respect to leadership, I am particularly pleased by the extent to which the Federal Government, at the urging of this Committee, is setting the example for the states and local governments in adopting seismic safety standards for both new and existing construction. Executive Order 12699, of January 5th, 1990, directed Federal agencies to issue regulations or procedures incorporating cost effective seismic safety measures for all new Federal buildings that are built, leased, assisted or regulated by the Federal Government.

In December of last year, we were able to report that all the affected Federal agencies have issued the required procedures or regulations, and that all have adopted one or more recommended minimum standards for seismic safety.

Further, by Executive Order 12941, issued December 1st, 1994 by the President, the President adopted minimum standards to be applied to the seismic safety of all existing federally-owned or leased buildings. It also directs agencies to survey their existing inventory against those standards for seismic risks and to report on their findings and on the estimated cost of mitigating unacceptable seismic risks in those buildings.

The idea behind the Executive Order is to systematically identify opportunities to upgrade and retro-fit. This process sets the example for upgrading critical facilities at risk in other building sectors as well.

Touching briefly on FEMA's program delivery responsibilities, we administer an annual grant program of $5.8 million to 35 states in Fiscal 1995 to support their earthquake hazards reduction activities, including training for architects and engineers, efforts supporting hazards identification and loss estimation techniques and the adoption and enforcement of seismic codes, response and recovery planning and education and public awareness. The funds are provided on a 50/50 matching basis and are distributed on a formula that takes into account the level of seismic hazard and population at risk.

We administer a national earthquake technical assistance contract that provides access to expertise in seismic matters on a short term basis to state and local governments. We also provide funding support to three major state earthquake consortia serving the northeast, central and western areas of the nation.

FEMA's education and public awareness activities under NEHRP include workshops conducted by the three building code organizations and the American Institute of Architects to acquaint builders, code officials and design professionals with the seismic aspects of the codes they use and enforce. We sponsor an annual workshop at which professionals in the field meet with state emergency management and hazard mitigation staff to exchange information and ideas.

We support courses presented at our Emergency Management Institute and in the field that promote knowledge of seismic hazards for state emergency managers, educators and facilities and lifelines managers. We have collaborated with the National Science Teacher's Association, the American Geophysical Union and others to develop and offer in-school courses for Grades K through 12, as well as a home study course in seismic safety.

Additionally, FEMA provides funding support to nationally recognized information and dissemination centers, including the National Center for Earthquake Engineering Research at the State University of New York at Buffalo, the Southern California Earthquake Center, the Earthquake Research Institute and the Natural Hazards Information Center at the University of Colorado.

Over the years, the agency has developed and published a series of documents, acknowledged as being authoritative in the field, that serve the purposes of heightening public awareness of the seismic hazard and measures that may be taken to mitigate it, disseminating the most current information on building practices and transferring technology into the built environment. Two major examples in this regard are the "NEHRP Recommended Provisions for Seismic Regulations for New Buildings," developed under contract by the Building Seismic Safety Council, which now forms the basis for the seismic portions of all three of the nation's model building codes, and the "Seismic Rehabilitation of Existing Buildings" with accompanying "Commentary," scheduled for completion in late 1997.

The latter documents will contain nationally-applicable consensus-backed criteria and allow practitioners to choose approaches consistent with different levels of seismic safety, as required by such considerations as geographic location, type of building and occupancy and building performance objectives.

Additionally, FEMA has contracted with the National Institute of Building Sciences to develop a nationally-applicable standardized methodology for estimating potential earthquake losses on a regional basis. This methodology will be offered to the states as a basis for the risk analyses that are incorporated in our new Performance Partnership Agreements that FEMA is negotiating with each of the states.

The research and studies performed by the other NEHRP agencies are the critical first step of a cycle that leads to the development of a resource document or a standard, such as the "NEHRP Recommended Provisions." However, the cycle often develops gaps when earthquakes present us with previously unforeseen problems.

To address them, FEMA is initiating what we call "problem-focused studies." A major example of this type of activity currently underway is the steel moment frame buildings study, which is examining the causes and cures relating to the unacceptable performance of steel moment frame connections in the Northridge earthquake. Other studies will examine the development of seismic building performance criteria and an improved set of seismic design maps.

In this very brief description of FEMA's responsibilities and activities under NEHRP, I hope I have conveyed the thought that the issues surrounding earthquake hazards reduction are large and pervasive. However, many of these issues are not unique to earthquake hazards, particularly those that involve developing and sustaining an awareness of the hazard and a commitment to take appropriate mitigating actions. This fact has been underscored during our development over the last year and a half of a National Mitigation Strategy in which we seek to provide a framework for a concerted effort to tackle some of these issues head-on.

A stronger mitigation emphasis is the best way to deal with the economic and social consequences of earthquakes.

Thank you, Mr. Chairman.

[The prepared statement of Mr. Moore follows:]

TESTIMONY OF

RICHARD T. MOORE

ASSOCIATE DIRECTOR FOR MITIGATION
FEDERAL EMERGENCY MANAGEMENT AGENCY

BEFORE THE

SUBCOMMITTEE ON BASIC RESEARCH

OF THE

COMMITTEE ON SCIENCE

UNITED STATES HOUSE OF REPRESENTATIVES

October 24, 1995

Mr. Chairman, Members of the Subcommittee, I am pleased to appear before this distinguished panel today to discuss the role of the Federal Emergency Management Agency in the National Earthquake Hazards Reduction Program, or NEHRP. I am Richard T. Moore, Associate Director for Mitigation at FEMA.

I applaud you for calling hearings at this time - a time when the Nation stands at a crossroads concerning our policy towards dealing with the impacts of natural hazards on our people, their property and our economy. In the last several years we have been beset with an unprecedented series of natural catastrophes, the costs of which were unthinkable only a decade ago. The litany of these events is well known to all of us: Hurricanes Hugo, Andrew, Iniki, Marilyn, and Opal; the Mid-West floods of 1993; and the Loma Prieta and Northridge earthquakes.

Of the natural hazards just listed, earthquakes, in spite of the advances made by the NEHRP agencies, present us with perhaps the greatest challenges, for several reasons. First, we are still learning when it comes to understanding completely the forces that generate earthquakes and the possible location and timing of their occurrence. Second, because of their comparative infrequency, it is difficult to raise and sustain a level of public concern necessary to carry hazard reduction programs forward. And third, we are still in a developmental stage when it comes to designing and building earthquake-resistant structures, and to rehabilitating the older buildings and infrastructure.

This is not to deny the impressive gains that have been made since the passage of the Earthquake Hazards Reduction Act of 1977; but to acknowledge the magnitude and complexity of the problems with which we continue to grapple.

The 1977 Act established a program involving four agencies; FEMA, the United States Geological Survey, the National Science Foundation, and the National Institute of Standards and Technology. Each of these agencies will describe its roles in, and contributions to, the NEHRP.

FEMA has a dual set of responsibilities under NEHRP. The first set is related to the role of lead agency for the program. In this regard, we are responsible for presenting a consolidated budget to the Office of Management and Budget, for overall program planning, for biennial reports to Congress, and for promoting the implementation of earthquake hazards reduction measures by all levels of government, standards and code organizations, and the construction sectors. The second set of responsibilities involves implementing hazard reduction activities, including providing grants and technical assistance to States and local governments, earthquake education and public awareness, development and dissemination of information on seismic-resistant building practices, earthquake disaster response planning, and integrating earthquake hazards reduction with other natural and technological hazards reduction techniques.

As I am sure you are aware, Mr. Chairman, the Administration received a letter in November of 1993 from several Members, raising a number of concerns about NEHRP, at least two of which related to lead agency functions - the lack of an overall strategic plan, and insufficient coordination among the agencies to shape a unified, coherent program. As you are aware, the Administration has completed a study of the program and is instituting changes to include more Agencies and to designate a Program Officer in FEMA to be responsible for overall program management. FEMA continues to share the vision of the Congress for NEHRP - a program that is more closely coordinated in the context of a clearly defined set of objectives - and pledges to exert every effort in the context of the Administration's decisions to make that vision a reality.

With respect to leadership, I am particularly pleased by the extent to which the Federal government, at the urging of this Committee, is setting the example for States and local governments in adopting seismic safety standards for both new and existing construction. Executive Order 12699 of January 5, 1990 directed Federal agencies to issue regulations or procedures incorporating cost-effective seismic safety measures for all new Federal buildings that are built, leased, assisted or regulated by the Federal Government. In

December of last year we were able to report that all of the affected Federal agencies have issued the required procedures or regulations and that all have adopted one or more of the recommended minimum standards for seismic safety. Further, by Executive Order 12941 of December 1, 1994, the President adopted minimum standards to be applied to the seismic safety of all existing Federally owned or leased buildings. It also directs agencies to survey their existing inventory against those standards for seismic risks and to report on their findings and on the estimated cost of mitigating unacceptable seismic risks in those buildings. The idea behind the Executive Order is to systematically identify opportunities for upgrade and retrofit. This process sets the example for upgrading existing critical facilities at risk in other building sectors as well.

Touching briefly on FEMA's program delivery responsibilities, we administer an annual grant program that provided $5.8 million to 35 States in FY 1995 to support their earthquake hazards reduction activities, including training for architects and engineers, efforts supporting hazards identification and loss estimation techniques and the adoption and enforcement of seismic codes, response and recovery planning, and education and public awareness. The funds are provided on a 50-50 matching basis, and are distributed on a formula that takes into account the level of seismic hazard and the population at risk. We administer a national earthquake technical assistance contract that provides access to

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Over the years, the Agency has developed and published a series of documents, acknowledged as being authoritative in the field, that serve the purposes of heightening public awareness of the seismic hazard and measures that may be taken to mitigate it, disseminating the most current information on building practices, and transferring technology into the built environment. Two major examples in this regard are the "NEHRP Recommended Provisions for Seismic Regulations for New Buildings," developed under contract by the Building Seismic Safety Council, which now forms the basis for the seismic portions of all three of the Nation's model building codes, and the "Seismic Rehabilitation of Existing Buildings" with accompanying "Commentary," scheduled for completion in late 1997. The latter documents will contain nationally-applicable consensus-backed criteria, and allow practitioners to choose approaches consistent with different levels of seismic safety as required by such considerations as geographic location, type of building and occupancy, and building performance objectives. Additionally, FEMA has contracted with the National Institute of Building Sciences to develop a nationally-applicable standardized methodology for estimating potential earthquake losses on a regional basis. This methodology will be offered to the States as a basis for the risk analyses that are incorporated in the Performance Partnership Agreements that FEMA is negotiating with the States.

The research and studies performed by the other NEHRP agencies are the critical first step of a cycle that leads to the development of a resource document or a standard - such as the "NEHRP Recommended Provisions." However, the cycle often develops gaps when earthquakes present us with previously unforeseen problems. To address them, FEMA is initiating what we call problem-focused studies. A major example of this type of activity currently under way is the Steel Moment Frame Buildings study, which is examining the causes and cures relating to the unacceptable performance of steel moment frame connections in the Northridge earthquake. Other studies will examine the development of seismic building performance criteria and an improved set of seismic design maps.

In this very brief description of FEMA's responsibilities and activities under NEHRP, I hope I have conveyed the thought that the issues surrounding earthquake hazards reduction are large and pervasive. They call for the best efforts on the part of Federal agencies, State and local governments, academia, and the engineering, design and construction professionals - all of whom are involved in one or more of the activities I have described. However, many of these issues are not unique to the earthquake hazard - particularly those that involve developing and sustaining an awareness of the hazard and a commitment to take appropriate mitigating actions. This fact has been underscored during our development of a National Mitigation Strategy, in which we seek to provide a framework for a concerted effort to tackle some of these issues head-on. A stronger mitigation emphasis is the best way to deal with the economic and social consequences of earthquakes.

At this time, we cannot predict when and where earthquakes will occur; however, we do know how to reduce their effects, based in large measure on the work done under the framework provided by NEHRP. In closing Mr. Chairman, I want to acknowledge and express appreciation for the leadership this Subcommittee has provided in this vital area. We look forward to your continued counsel and support.

Mr. BAKER. Thank you, Mr. Moore. Dr. Hamilton.

STATEMENT OF DR. ROBERT M. HAMILTON, PROGRAM COORDINATOR FOR GEOLOGIC HAZARDS, UNITED STATES GEOLOGICAL SURVEY

Mr. HAMILTON. Mr. Chairman, and members of the Subcommittee, I welcome this opportunity to appear before you on the reauthorization of NEHRP and specifically to discuss the role that the Geological Survey plays in that program.

I believe that, on the whole, NEHRP is one of the most effective programs conducted by the Federal Government and that it constitutes an example of successful collaboration with state and local governments, academia and the private sector. In less than 20 years, the program has developed new earthquake knowledge that is steadily being implemented through improved building standards and land use and better preparedness.

It is remarkable to recall that when NEHRP began, we did not understand the cause of the three magnitude 8 earthquakes that struck at New Madrid, Missouri in 1811 and 1812. And, now we do.

We misperceived the earthquake threat to the Seattle-Tacoma region. And, now we have a sound basis for action.

We had few recordings of strong ground motion for engineering design. And, now we have a wealth of records.

Nevertheless, much remains to be done. As one example of our challenges, we are only now learning about the threat of blind thrust faults—that is, faults that are buried and cannot be seen at the surface—in the Los Angeles area. One of these faults caused the Northridge earthquake.

The USGS role in NEHRP—and I do believe that the roles are fairly well specified—is to assess earthquake hazards, including understanding the cause of earthquakes and the nature of their effects. Such information provides the basis for all strategies to mitigate earthquake losses.

Our role complements that of our NEHRP partners and is carried out by both government and non-government experts who are coordinated by means of a common program plan.

We recognize that although NEHRP has made great progress much remains to be done. In particular, there is dissatisfaction at the pace of implementing our findings.

Now, this situation is referred to in the OTA report, as you heard, as an implementation gap. In addressing this problem, it is essential to recognize that the authority for most implementation actions rests at local levels of government or in the private sector; therefore, closing the gap involves political issues concerning mandates and incentives as well as federal/state roles.

The most significant domestic earthquake since the last NEHRP reauthorization hearings was at Northridge, California on January 17th, 1994. It was the most costly earthquake in U.S. history, causing estimated losses of about $20 billion.

But, it could have been much worse. Scientific and engineering information from NEHRP helped to limit the loss of life and property.

In other parts of the world where programs such as NEHRP do not exist, similar sized earthquakes have caused thousands of deaths and enormous damage. Just nine months ago, the heavily industrialized center of Kobe, Japan was struck by a tragic earthquake.

The extensive damage initially raised many questions about the ability of the engineering community to mitigate against such losses. But, extensive surveys of the damage revealed that the more recently constructed buildings fared much better than the older ones, demonstrating the effectiveness of modern building codes.

Returning to the United States, in contrast to our state of knowledge in California, we are only just now beginning to understand the details of seismic source zones in other parts of the country. For example, in the central U.S., in the New Madrid zone, as I mentioned before, three magnitude 8 earthquakes occurred there between 1811 and 1812. How often such earthquakes could occur has been completely unknown.

Using geologic techniques, we now know that such large earthquakes are recurrent events with at least four in the past 2,000 years. Further, in the Wabash Valley in Indiana, there is now evidence of seven large earthquakes in the past 20,000 years based on geologic studies.

In the Pacific Northwest, during the last three years, we have found that, first, a major earthquake of about magnitude 7 occurred on the Seattle fault 1,100 years ago in what is now the heart of the city's industrial district. Another fault on South Widbey Island has been identified as a potential site for similar large magnitude earthquakes.

And, studies in the Portland, Oregon area have confirmed that the Portland Hills fault is a major fault zone capable of producing a magnitude 7 event.

On a national scale, the USGS is producing probabilistic seismic hazard maps as part of the 1997 building code revisions. The project involves extensive consultation with researchers, practicing design engineers, and state, regional and local governments for each region in the nation in order to obtain consensus on the methodology used in constructing the maps.

With respect to public information, over the last five years the USGS and its partners have published newspaper inserts for the San Francisco Bay area, the northern coast of California and Alaska. The northern coast insert was so popular that it has already been revised and reprinted.

In each insert, we explain the earthquake hazard and risk, show a homeowner simple cost-effective mitigation steps and list other information sources.

In Southern California, in cooperation with the National Science Foundation through its Southern California Earthquake Center and FEMA, we are in the process of distributing 2 million copies of "Putting Down Roots in Earthquake Country." It outlines a clear strategy for families to greatly improve their chances of surviving the next Southern California earthquake and significantly reducing losses to their property.

Looking ahead, the USGS believes that FEMA's National Mitigation Strategy provides a coherent framework for coordination among all organizations concerned with the earthquake threat, particularly because earthquake issues can best be addressed in a multihazard context.

Let me close by noting that projects were begun this year by the state geological surveys of California and Oregon with FEMA and state funding to map the Northridge earthquake area and Portland, Oregon, respectively, to carry out state-mandated efforts to reduce future earthquake losses. This shows that research results from NEHRP are being brought to bear on local decisions.

Similar efforts are underway elsewhere. This work would not have been possible without the results from NEHRP. And, it indicates the accelerating pace of implementation.

Thank you, Mr. Chairman.

[The prepared statement of Dr. Hamilton follows:]

TESTIMONY OF DR. ROBERT M. HAMILTON
PROGRAM COORDINATOR FOR GEOLOGIC HAZARDS
U.S. GEOLOGICAL SURVEY

REAUTHORIZATION HEARING
BEFORE THE
SCIENCE SUBCOMMITTEE ON BASIC RESEARCH
OF THE
U.S. HOUSE OF REPRESENTATIVES
October 24, 1995

Introduction

Mr. Chairman, and members of the Subcommittee, I welcome the opportunity to appear before you on the reauthorization of the National Earthquake Hazards Reduction Program (NEHRP) and the role that the U.S. Geological Survey (USGS) serves in the program. I believe NEHRP is one of the most successful programs conducted by the Federal Government, and it constitutes an example of successful collaboration with State and local governments, academia, and the private sector. In less than 20 years, the program has developed new knowledge for countering the impacts of earthquakes; knowledge that is rapidly being implemented through improved building standards, land use, and better preparedness.

It is remarkable to recall that when NEHRP began:

- We did not understand the cause of the three magnitude 8 earthquakes that struck the center of our country at New Madrid, Missouri, in 1811-1812, and now we do,

- We misperceived the earthquake threat to the Seattle-Tacoma region, and now we have a sound basis for action, and

- We had few recordings of strong ground motions for engineering design, and now we have a wealth of records.

These are just a few examples of the many NEHRP successes; however, much remains to be done. As one example of our challenges, we are only now learning about the threat of blind thrust faults (faults that are buried and therefore cannot be seen at the surface) in the Los Angeles area.

The USGS role in NEHRP is to assess earthquake hazards, including understanding the cause of earthquakes and the nature of their effects. This information provides the basis for all strategies to mitigate earthquake losses. Our role complements that of our Federal partners--the Federal Emergency Management Agency (FEMA), the National Science Foundation (NSF), and the

National Institute of Standards and Technology (NIST). The USGS role is carried out through both internal and external program components which are closely integrated through a common prospectus of activities. In this way, we are able to apply the best talents of the academic, private, and other governmental sectors to NEHRP.

We recognize that although NEHRP has made great progress, much remains to be done. There is dissatisfaction at the pace of implementing our findings; this situation is referred to in the Office of Technology Assessment (OTA) report on NEHRP as an "implementation gap." As the authority for most implementation rests at local levels of government or in the private sector, closing the "gap" involves political issues concerning mandates and incentives, as well as Federal-State roles. In any case, the Federal Government must work more effectively with these sectors to ensure transfer of sound information as a basis for their decisions. The recently completed office of Science & Technology Policy report on NEHRP provides a strategy for meeting our future challenges.

Northridge, California, Earthquake: An Urban Disaster

The most significant domestic earthquake since the last NEHRP reauthorization hearings was at Northridge, California, on January 17, 1994. The violent shaking caused by the M6.7 Northridge earthquake shocked the Los Angeles region, and the damage it produced startled the whole nation. It was a moderate earthquake in size, but since it occurred directly under the populated San Fernando Valley, it had an immense impact on the people and structures of the Los Angeles area. The 10 to 20 seconds of strong shaking at 4:30 a.m. collapsed buildings, brought down freeway interchanges, and ruptured gas lines that exploded into fires. But the early morning occurrence was fortuitous, because many of the large buildings and parking structures that collapsed were unoccupied and traffic was very light on the freeway overpasses that fell.

The M6.7 Northridge event was the most costly earthquake in US history, causing estimated losses of $20 billion. Insured losses have reached $12 billion and are still climbing. There were 57 deaths and over 9000 injuries attributed to the earthquake, as well as 20,000 people displaced from their homes. Over 1600 buildings were "red-tagged" as unsafe to enter. Another 7300 buildings were restricted to limited entry ("yellow-tagged"), and many thousands of other structures incurred minor damage. Freeways collapsed at 7 sites and another 170 bridges had varying amounts of observable damage.

Despite these huge losses, information gained from scientific efforts of the NEHRP, combined with some of the best engineering of structures in the US, helped to limit the loss of life and property. In other parts of the world where programs such as NEHRP do not exist, similar sized earthquakes, for example in India (1993) and Armenia (1988), have caused thousands of deaths and produced much more widespread damage to structures.

With emergency supplemental funding provided to the NEHRP agencies, USGS scientists have redirected their work in Fiscal Years 1995 and 1996 to study the Northridge earthquake and incorporate their findings into products that will help to reduce losses from future earthquakes in the San Fernando Valley and the Los Angeles basin. For example:

- Seismic studies of the thousands of aftershocks clearly showed the extent of the faulting during the earthquake. The concentration of aftershocks shows a rupture plane about 15 x 10 km that slants downward toward the south from a depth of 5 km to about 18 km.

- Geologic investigations following Northridge confirmed that the fault did not break the surface. This points to the difficulties in identifying "blind thrust" faults. Efforts are underway to map and identify many of these blind structures in the greater Los Angeles region.

- Seismologists are involved in detailed studies of the earthquake source. This event caused very large ground motion with peak accelerations of 0.5 to 1.0 g in the Northridge area, decreasing to 0.1 g at distances of about 50 km. These high levels of ground motion and the resultant wide-spread damage emphasize the need for a better understanding of how the earthquake source produces these large ground motions, and to determine whether or not such ground motion is typical of all California earthquakes.

- Geologists mapped thousands of landslides and rock falls caused by the earthquake. Data gathered from this earthquake will be used to make maps of landslide hazards in future earthquakes.

- Following the earthquake, geologists identified areas of liquefaction and lateral spreading. Data gathered from this earthquake will be used to make maps of liquefaction hazards in future earthquakes.

The type of fault that produced the Northridge earthquake is not unique to the San Fernando Valley. There is geologic evidence that several blind thrusts in the Los Angeles basin are capable of producing events even larger than Northridge. Large earthquakes on these faults threaten densely populated areas, including the high-rise buildings in downtown Los Angeles. Ongoing USGS research also focuses on the San Andreas fault near San Bernardino and San Francisco, where the Hayward fault passes through the densely populated areas of Oakland and East Bay communities. The Puget Sound basin is also suspected of having blind thrusts, and research is underway to examine this possibility.

Our studies at Northridge are being published rapidly. We plan to complete publication of our major studies during the current fiscal year (1996). In outlining the completion of the Northridge studies, we have developed a suite of products tailored to meet the needs of the primary users of this work--the people who live and work in the greater Los Angeles area. Our products include a series of maps in GIS format that explain what happened in the Northridge earthquake and help predict effects of future scenario earthquakes. These maps and predictions, which will serve as the foundation for helping the citizens and businesses of the Los Angeles area develop loss reduction efforts to lower future urban earthquake losses, include: site response, damage, active faulting, liquefaction, landslide, and ground motion time histories of scenario earthquakes.

Kobe, Japan: Important Lessons for the United States

Just 9 months ago, the heavily industrialized center of Kobe was struck by a tragic earthquake. This earthquake initially raised many questions about the risks of large urban earthquakes and the ability of the engineering community to mitigate against these risks. As the attention in Kobe shifted from relief to recovery, American investigators had the opportunity to visit the city and examine at first hand this disaster. In the midst of the ruin, as in most great disasters, has come a powerful lesson for those in other areas subject to large earthquakes: it is necessary to continually work to understand regional seismic hazards and to incorporate this understanding into building codes and construction practices.

In a sample of 83 buildings constructed from 1965 to the present, engineers found a clear correlation in building performance with the date of construction. For buildings in the sample built before 1965, severe damage levels (collapse) reached about 60% and moderate damage levels about 20%, while slight or no damage levels were limited to 10%. However, because of changes in seismic construction codes and practices after 1980, there was a dramatic improvement in building performance clearly related to date of construction. No buildings in this latter sample had severe or collapse failure, and moderate damage levels were below 20%.

Pacific Northwest and Central United States: Seismic Source Zones

The Northridge earthquake demonstrated the necessity of understanding source zones in estimating the seismic hazard of a region and the Kobe earthquake underscored the necessity of updating building codes as scientific understanding progresses. Although in the case of Northridge, the actual fault that broke during the earthquake had not been described beforehand, we had a good working understanding of the causes of earth strain accumulation in the Los Angeles area before the event. We can use the Northridge earthquake to improve this understanding by incorporating blind thrusts as an important refinement.

In contrast to our state of knowledge in California, we are just now beginning to understand the details of seismic source zones in the rest of the country. Here are two examples:

(1) Central United States

In the Central United States, near New Madrid, Missouri, the country experienced a series of great earthquakes between 1811 and 1812. One of the most important parameters in estimating earthquake hazards, namely the frequency of occurrence of these large events, has been completely unknown. To address this problem, the USGS has used paleoseismic techniques to search for evidence of past earthquake activity in the multistate region.

The Central United States differs from California in that: 1) faults are almost never exposed at the Earth's surface, 2) there have been only two decades of research in the region versus nine decades of relatively intense research in California, and 3) historically, there has been a lower level of widely scattered seismicity.

We now know that large earthquakes, such as those in 1811 and 1812, are recurrent events, with at least four in the past 2000 years. Further, in the Wabash Valley seismic zone in Indiana, there is now evidence of seven large earthquakes in the past 20,000 years.

(2) Pacific Northwest

In the Pacific Northwest, paleoseismic studies have changed our understanding of the regional framework for earthquake hazards. The Pacific Northwest region has three fundamental source zones for earthquakes: 1) earthquakes on the long, downward sloping fault between the Juan da Fuca plate and the North American plate, 2) shallow, crustal earthquakes within the North American plate, and 3) deep earthquakes within the Juan da Fuca plate.

Before our paleoseismic studies in the region, the possibility of large, deep earthquakes was not recognized in earthquake hazard assessments. As evidence for such events has grown, their potential consequences became one of the driving forces to improve the seismic provisions of building codes across western Oregon and southwestern Washington.

The incorporation of our research results into seismic building code provisions has not ended the need for better understanding of seismic source zones in the Pacific Northwest region. During the last 3 years, we have found that:

- A major earthquake (magnitude 7) occurred on the Seattle fault about 1100 years ago. That event ripped through what is now the heart of the city's industrial district, probably on a fault parallel to the Mercer Island floating bridge. The South Widbey Island fault has been identified as a possible candidate for similar large magnitude earthquakes.
- The West Rainier seismic zone, just west of Mount Rainier National Park, poses not only a seismic hazard, but the threat of landslides and avalanches off the high slopes of Mount Rainier.
- Geophysical studies in Portland, Oregon, have confirmed that the Portland Hills fault is a major fault zone capable (because of its length) of producing a magnitude 7 event.

National Probabilistic Seismic Hazard Map

NEHRP research on earthquake recurrence, seismic sources, and seismic wave propagation are all used by the USGS in the construction of national and regional probabilistic seismic hazard maps.

These maps are used in planning by industry and the public, and in turn by the Building Seismic Safety Council (BSSC) as part of the 1997 NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings.

The National Probabilistic Seismic Hazard Map project strategy for the 1997 Building Codes involves extensive consultation with NEHRP researchers, practicing design engineers, and state, regional, and local government for each region of the nation in order to obtain consensus on the geologic parameters and the methodology used in constructing the national and regional probabilistic seismic hazard maps. The goal is to produce a set of probabilistic hazard maps to be available in April 1996 that has the broad support appropriate for economically sensitive regulations such as building codes. In late 1994 and early 1995, the project held a series of regional workshops focusing on refining the characterization of seismic sources and ground motion attenuation in that region. Workshop attendees--earth scientists, practicing design practitioners, state and local officials, and representatives of the BSSC--were presented preliminary maps and asked to provide input and advice on the input data and map construction methodology.

Improved Technology Transfer: The Applied Technology Council

Established by the Structural Engineers Association of California (SEAOC) in 1971, the Applied Technology Council (ATC) is a nonprofit corporation to help the design practitioner in structural engineering keep abreast of and effectively use technological developments. In 1992, the USGS signed a cooperative agreement, ATC-35, with ATC to improve the transfer of NEHRP research results to the engineering design practice. A steering committee of USGS, academic, and private consulting company scientists and engineers provides guidance to the practicing engineers managing ATC-35.

As the initial activity in the project, ATC conducted a series of five regional seminars: Los Angeles, California on January 26, 1994; San Francisco, California on January 27, 1994; Seattle, Washington on February 2, 1994; New York, New York on February 9, 1994; and Memphis, Tennessee on February 10, 1994. Each seminar provided comprehensive, practical region-specific information on earthquake potential and the characteristics of expected ground shaking, with a special emphasis on issues relevant to the determination and mapping of design ground motions. Each seminar was attended by hundreds of practicing engineers, and the proceedings of the seminars were published in 1994.

The next phase of ATC-35 will focus on a Ground Motion Initiative to promote coordination between the USGS and the earth science communities and the engineering communities in developing the next generation of seismic design practices and regulations. The project will build on the structural engineering community's recognition of the need to reconsider the entire approach to seismic design practices and regulations by using the principles of mechanics to assess the demands made on structures during earthquakes and the capacities of materials and structures to response. This new coordination between the USGS and the engineering community has taken on both increased importance and urgency in the aftermath of the Kobe earthquake.

Regional Needs

The USGS has placed high priority on studies in four earthquake-prone regions: the Pacific Northwest (including Washington, Oregon and Alaska), the San Francisco Bay area, southern California, and the Central U.S. In determining where to focus USGS efforts, we considered the seriousness of the earthquake hazard for a given region, and the population density and the economic infrastructure at risk in that region. For each region, the USGS appointed an on-site coordinator, charged with identifying the needs of end users in the region and developing a comprehensive program to meet these needs. In addition, the USGS continues to support work in other geographic areas of high to moderate seismic risk such as the Wasatch fault zone of Utah, the southeastern and northeastern regions of the US, and Hawaii.

In FY 1995, we realigned our program in accordance with recent major studies and recommendations for changes in the NEHRP. In this light, we are committed to continue to operate a National Program with strong regional emphasis in the Pacific Northwest (including Alaska), Northern California, Southern California, and Central United States. Outside of these four regions, we will continue program development in states in the Intermountain West (Utah, Idaho, Montana, Nevada), Northeastern States (New York, New England), and Hawaii. We will continue to support promising selected studies in these areas that will help these states understand their earthquake hazards.

The USGS has reshaped its management and operational structure to accelerate progress toward the USGS NEHRP goals. In 1990, the USGS conducted a major strategic planning effort. The resulting strategic plan, "Goals, Opportunities and Priorities for the USGS Earthquake Hazards Reduction Program", defines four goals for the USGS component of NEHRP, proceeding from basic scientific investigations to implementation of research results. The fourth goal, "using research results" is a strong commitment to foster the implementation of research in loss reduction, preparedness, and emergency response programs.

Putting Down Roots in Earthquake Country

As the country slowly shifts toward a stronger emphasis on mitigation, the need to foster a broadly based understanding of the benefits of mitigation is more urgent then ever. Unless the benefit of mitigation is understood, the Nation will always be susceptible to a totally unexpected disaster tax. Over the last 5 years, the USGS and our partners have written and published newspaper inserts in the San Francisco Bay area, for the Humboldt coast of California, and in Alaska. The Humboldt coast insert was so popular that it has already been revised and reprinted. In each insert we explain the earthquake hazard and risk, show a homeowner simple, cost-effective mitigation steps, and list other information sources.

A project in Southern California demonstrates our commitment to reach all persons who call earthquake country home. We have just distributed 2 million copies of "Putting Down Roots in Earthquake Country". This booklet has set a new standard for clarity and purpose in communicating technical information to the general public. Reviewers have compared this booklet favorably with the publication series produced by **Sunset Magazine**. Within the atmosphere of heightened earthquake awareness that exists in Southern California, it outlines a clear strategy for families to greatly improve their chances of surviving the next southern California earthquake and significantly reducing losses to their homes and property.

Conclusion

We have outlined a vigorous agenda to build on NEHRP accomplishments over the coming years. In building this agenda, we have incorporated suggestions for new directions arising from national reviews of NEHRP, including those done by the Office of Science and Technology Policy, the Office of Technology Assessment, FEMA-sponsored reviews of NEHRP, and our own strategic planning effort. Looking ahead, FEMA's National Mitigation Strategy provides a coherent framework for coordination among all organizations concerned with the earthquake threat, particularly because earthquake issues should be addressed in a multihazard context.

The understanding of earthquakes by the Nation's populace of 250 million varies widely, but the public's awareness of hazards is improving. The capacity to construct earthquake-resistant buildings and lifelines and to avoid hazards through wise land use in earthquake-prone regions varies greatly from state to state, or even from one local jurisdiction to another, but it is also improving. Additional gains will be made as scientific understanding of the local earthquake threat improves and this, in turn, will increase the quality and effectiveness of these local risk reduction measures.

Let me close by noting that projects were begun this year by the state geological surveys of California and Oregon with FEMA and State funding to map the Northridge earthquake area and Portland, respectively, to carryout state-mandated efforts to reduce future earthquake losses. This positive development demonstrates how research results from NEHRP are being brought to bear on local decisions. Similar efforts are underway elsewhere. This work would not have been possible without the results from NEHRP, and it indicates the accelerating pace of implementation.

Mr. BAKER. Thank you, Dr. Hamilton. Dr. Bordogna.

STATEMENT OF DR. JOSEPH BORDOGNA, ASSISTANT DIRECTOR FOR ENGINEERING, NATIONAL SCIENCE FOUNDATION

Mr. BORDOGNA. Mr. Chairman, members of the Committee, thank you for giving me this opportunity to discuss the role of the National Science Foundation in NEHRP.

NSF's participation in this important activity complements our overall mission of discovery. And, we've always welcomed being an integral part of the NEHRP partnership.

The leadership of the United States in earthquake science and engineering is recognized the world over and is reflected in our contribution to new knowledge on the causes and effects of earthquakes, other natural disasters and their mitigation. NSF's contribution to NEHRP starts with the funding of research that leads to new discoveries and technologies, including research in the disciplines of earth sciences, earthquake engineering, the social sciences and integrated multi-disciplinary research.

The fundamental research supported by NSF, which is performed by non-government persons and groups, complements the internal research activities carried out by such agencies as USGS and NIST. This research is intended to provide part of the basis for earthquake hazard mitigation and preparedness actions undertaken by FEMA and other Federal and state agencies, as well as further efforts undertaken by local officials and such professionals as architects, structural engineers and planners.

NSF enables researchers to advance knowledge through both individual investigator awards and group awards such as centers. Individual investigator awards comprise the largest number of awards made by NSF. And, they permit researchers to pursue lines of inquiry that their vision leads them to believe will contribute to fundamental knowledge.

Group awards supported by NSF tend to focus on problems of multidisciplinary nature. For example, since 1986 NSF has supported the National Center for Earthquake Engineering Research at the State University of New York at Buffalo. This center was established to pursue a holistic, multi-disciplinary approach toward investigating the impact of earthquakes on the built environment.

The Southern California Earthquake Center was established as one of NSF's science and technology centers, with NSF and USGS funding at the University of Southern California, in 1991 for the purpose of promoting and integrating science related to earthquake hazards estimation and reduction. Both of these centers have formed partnerships with many relevant public and private sector groups, which significantly contribute to their ability to further both knowledge discovery and utilization.

In addition to experimental research at a scientist's lab bench, new knowledge is also generated in the earthquake field through post-earthquake investigations on site. Earthquake events serve as natural laboratories for research, providing the opportunity to make new observations and to test insights gained from analytical and experimental research performed in a laboratory.

The more than 100 studies on the 1994 Northridge earthquake that was supported by NSF and its NEHRP partners are yielding valuable information on the causes and consequences of earthquakes, especially the impacts these events have had on steel frame buildings, which was mentioned earlier. Some of these types of buildings were surprisingly damaged during both the Northridge and the Kobe earthquakes.

The Great Hanshin earthquake struck Kobe, Japan exactly a year after the Northridge earthquake and provides another example for discovering important lessons about such events. NSF has funded individuals and teams of researchers who are investigating a range of issues that have relevance to earthquake hazards reduction in both U.S. and Japan, including the performance of soils and buildings, the impact of the earthquake on civil infrastructure systems generally, and emergency response.

In the months ahead, NSF will continue to support promising new efforts to learn from the Great Hanshin earthquake.

Finally, while NSF's primary role in NEHRP is knowledge generation, it also contributes to knowledge integration and utilization through its support of the education of the next generation of professionals in the field and support of information dissemination clearinghouses and other outreach activities.

My final comment concerns research facilities. Because of their importance for the research enterprise, NSF gives considerable attention to the physical infrastructure necessary for performing research. NSF has provided funds for many of the research facilities using earthquake engineering research in the U.S. today and for their periodic upgrading.

For example, NSF recently supported a major upgrading of the earthquake simulator at the University of California at Berkeley, which is the largest shaking table in the U.S. for testing structural models. NSF, thus, concurs with the report prepared by the Earthquake Engineering Research Institute regarding the continuing importance of experimental earthquake research and the conclusion that, while newer and larger facilities would benefit the field in significant ways, highest priority should be given to updating extant facilities, as has been done in the Berkeley case. These facilities have contributed to the development of new structural design approaches, such as base isolation systems, and provide a part of the knowledge base for improvements in building codes.

NSF also agrees with the report's conclusion that the lack of any needed laboratory resources can be partially overcome through cooperation with other countries that have required facilities.

That concludes my oral statement. Thanks, very much.

[The prepared statement of Dr. Bordogna follows:]

Testimony of Dr. Joseph Bordogna

Assistant Director for Engineering

National Science Foundation

Before The

Subcommittee on Basic Research

Committee on Science

House of Representatives

October 24, 1995

INTRODUCTION

Mr. Chairman and distinguished members of the Subcommittee:

Thank you for giving me the opportunity to discuss with you the role of the National Science Foundation in the National Earthquake Hazards Reduction Program (NEHRP). NSF's participation in this important activity complements our overall mission, and we have always welcomed being an integral part of the NEHRP partnership, which was initially formed in 1977. The leadership of the U.S in earthquake science and engineering is recognized the world over and is reflected in our contribution to knowledge about the causes and effects of earthquakes and in the development and utilization of innovative mitigation strategies and tools that facilitate more effective earthquake hazard reduction in the Nation. We look forward to working with the other NEHRP agencies in meeting the future challenges posed by seismic hazards to our society and other parts of the world and in implementing lessons learned from such recent events as the January 17, 1994, Northridge earthquake and the Great Hanshin earthquake that struck Kobe, Japan on January 17, 1995.

Since its creation in 1950, the National Science Foundation has attempted to serve the Nation by furthering the development of scientific and engineering knowledge and the education and training of future generations of scientists, engineers and mathematicians. NSF does this by funding research in the scientific and engineering disciplines and in mathematics, by providing support for related educational activities, and by integrating the two.

Our basic mission, which was given to us by Congress, is to serve the Nation by furthering the progress of science and engineering. This challenge requires that the agency gives appropriate attention to the evolving needs of our society. Our vision and strategic plan, as set forth in the report entitled "NSF In A Changing World," identifies three basic goals for the agency: (1) Enable the U.S. to uphold a position of world leadership in all aspects of science, mathematics and engineering, (2) Promote the discovery, integration and employment of new knowledge in service to society, (3) Achieve excellence in U.S. science, mathematics, engineering, and technology education at all levels. The earthquake-related activities at NSF embody all of these goals, including the advancement of knowledge through university research in the earth sciences and engineering which is utilized by design and other professionals to promote seismic safety.

To achieve these goals, NSF follows core strategies which involve the development of intellectual capital, strengthening the physical infrastructure of science and engineering, integrating research and education, and promoting partnerships. NSF's earthquake research, education and information dissemination activities, which are carried out in partnership with NEHRP and other relevant agencies and groups, exemplify these strategies and are part of the agency's response to the changing needs of society and the role assigned to NSF by Congress.

Research and Knowledge Creation

NSF's contribution to NEHRP starts with the funding of research that leads to new discoveries on the causes and consequences of earthquakes, including research in the disciplines of earth sciences, earthquake engineering, the social sciences, and integrated multidisciplinary research. Consistent with NSF's overall goals, one of our concerns is that we continue to enable the earthquake research community to maintain its rank in the forefront of the field. This will allow the U.S. research community to address the needs of our society, work cooperatively with other leading countries, and also allow the U.S. to continue to be globally competitive in those industries, such as construction, that play a prominent role in earthquake hazard reduction.

Earth science research is funded through the Directorate for Geosciences, and earthquake engineering and earthquake-related social science research are supported in the Directorate for Engineering. The research supported by NSF complements the internal research activities carried out by such agencies as USGS and NIST. This research is intended to provide part of the basis for earthquake hazard mitigation and preparedness actions undertaken by FEMA and other federal and state agencies, as well as further efforts initiated by local officials and such professional groups as architects, engineers and planners.

NSF enables researchers to advance knowledge through both individual investigator awards and group awards such as centers. A merit review system is utilized to make decisions regarding the unsolicited proposals NSF receives from universities and other organizations. Individual investigator awards comprise the largest number of awards made by NSF and they permit researchers to pursue lines of inquiry that they feel will add to fundamental knowledge or contribute to the solution of particular problems.

Group awards supported by NSF often focus on problems of a multidisciplinary nature, such as are found in the earthquake field. For example, since 1986 NSF has supported the National Center for Earthquake Engineering Research (NCEER) through the Directorate for Engineering. NCEER, which has its administrative headquarters at the State University of New York at Buffalo, was established to pursue a holistic approach to earthquake research. Such an approach, which involves collaboration between seismologists, earthquake engineers and social scientists, has produced new insights on the impacts of earthquakes on the built environment and institutional systems and on cost-effective countermeasures for dealing with them

In collaboration with USGS in 1991, NSF established the Southern California Earthquake Center (SCEC) for the purpose of promoting and integrating science related to earthquake hazard estimation and reduction in that region. Similar to NCEER, SCEC is a consortium of institutions and is administered through the University of Southern California. Through its research, including investigations of such recent events as the Northridge earthquake, SCEC has contributed significantly to a new understanding of the earthquake hazard in southern California by combining insights from seismicity, new geodetic technology, new geologic discoveries, and local site conditions in an innovative framework of earthquake hazard evaluation.

Both of these centers have formed partnerships with many relevant groups, which significantly contribute to their ability to further both knowledge discovery and utilization and the leveraging of scarce resources. Other sources of support for NCEER include the State of New York, FEMA and private sector organizations such as IBM. SCEC receives additional resources from USGS, FEMA and the State of California.

New knowledge is created by NSF-funded projects through a combination of analytical, computational, experimental and field studies. Earthquake events serve as natural laboratories for research, providing the opportunity to make new observations and for testing insights gained from analytical and experimental research. For example, studies supported by NSF on the 1989 Loma Prieta earthquake in collaboration with USGS have advanced the understanding of such events and resulted in the development, testing and utilization of alternative structural design and construction practices for new and extant buildings and civil infrastructure systems. Similarly, the more than one hundred studies on the 1994 Northridge earthquake that were supported by NSF and its NEHRP partners are yielding valuable information on the causes and impacts of earthquakes, including the impacts on steel frame buildings, that can be utilized to further earthquake hazard mitigation in California and the rest of the Nation. Individual investigators as well as groups of researchers working in teams have contributed to these important efforts. Through conferences and other collaborative efforts the NEHRP agencies are encouraging Northridge researchers to make the results of their investigations available to architects, engineers, building officials, emergency managers and other potential end-users in both the public and private sectors.

The Great Hanshin earthquake struck Kobe, Japan on January 17, 1995, exactly a year after the Northridge earthquake, providing another opportunity for NSF to enable the research community to discover important lessons from a significant event. Funding has been made available to individuals and teams of researchers to investigate a range of issues that have relevance to earthquake hazard mitigation in both Japan and the U.S., including the performance of soils and buildings, impacts of the earthquake on civil infrastructure systems, and emergency response. This work, some of which commenced a few hours after the earthquake, is being carried out collaboratively by U.S. and Japanese researchers. Participating in the initial investigative response was a group of 40 U.S. scientists, engineers and practitioners led by the Earthquake Engineering Research Institute who were attending an NSF co-sponsored earthquake workshop on urban earthquake hazard mitigation in nearby Osaka. This group's efforts to collect valuable perishable information on the earthquake were followed by more in-depth research activities sponsored by NSF and other NEHRP agencies. In the months ahead, NSF expects to continue to support promising new efforts to learn from the Great Hanshin earthquake.

Furthering Implementation Through Education and Information Dissemination

NSF also contributes to NEHRP and the Nation through its education and dissemination efforts. Such activities are perhaps most effective when they are combined with the research process, as encouraged by NSF. However, NSF supports a mix of education and information dissemination activities in order to further the utilization of extant and emerging knowledge.

Recipients of research awards at educational institutions, both individual investigators and research teams, are expected to devote significant time to training the next generation of researchers and practitioners. Thus, on most earthquake-related projects funded by NSF, students actively participate in the on-going research process. Vital training is provided in this fashion for both undergraduate and graduate students and provides a foundation for their subsequent professional involvement in the creation and application of knowledge on earthquake hazards. Such intellectual capital development enables the U.S. to stay in the forefront of those fields relevant to earthquake research and earthquake hazard reduction.

NSF grantees also frequently enhance implementation of the knowledge and technologies they produce by taking various proactive actions in addition to such standard efforts as publishing their results in professional and technical journals. These include: serving as consultants to public and private sector groups on geotechnical, structural design, emergency preparedness and other issues; including potential users on their research projects; appointing users to project advisory committees; and participating on code groups.

NSF also furthers the utilization of knowledge and professional development in the earthquake field through the support of seminars, workshops and conferences and information dissemination clearinghouses, which are increasingly supported in collaboration with other NEHRP agenciesm, as well as other federal agencies. Among the major information clearinghouses supported by NSF in this field are the two branches of the National Information Service for Earthquake Engineering at the University of California, Berkeley and the California Institute of Technology and the Natural Hazards Information Center at the University of Colorado, Boulder. In addition, both SCEC and NCEER have major information dissemination programs.

NSF also continues to work in partnership with professional organizations and associations that can serve as links between knowledge producers and users. Such organizations include the Earthquake Engineering Research Institute, the Applied Technology Council, the Building Seismic Safety Council, and the American Society of Civil Engineers. These organizations are important in developing a quality research agenda and serving as utilization catalysts.

NEHRP to NEP

NEHRP has been a very successful partnership since its inception in 1977. The synergism resulting from this collaboration among FEMA, USGS, NIST, and NSF has contributed to such significant outcomes as increased knowledge about the causes and consequences of earthquakes, the development of more effective approaches to designing new structures and retrofitting existing ones, improvements in building codes and their increased adoption by vulnerable communities, and increased preparedness and mitigation actions across the U.S. There is also every evidence that NEHRP is increasingly reaching out to more stakeholders, including other federal agencies, state and local government, and practitioners in the private sector, thus laying the basis for an even more effective research and implementation enterprise.

As damaging and disruptive as such recent events as the Loma Prieta and Northridge earthquakes have been, they have been far less destructive and caused fewer casualties than similar events that have occurred in other countries. Such factors as timing and location obviously played some role in these differential impacts. However, it is generally agreed that some of the differences can also be attributed to the combined efforts of state, local and private sector decision makers and NEHRP, which have made some communities in this country less vulnerable to seismic hazards than those in some other countries.

Yet, though we conclude that NEHRP, as it has worked with other relevant groups, has been a success story, much remains to be done. Thus we might ask: What changes might make NEHRP even more successful in the future? We feel that the recommendations outlined in the recently completed report of the National Earthquake Strategy Working Group, "Strategy For National Earthquake Loss Reduction," provide a sound basis for making the Nation's earthquake risk reduction efforts even more effective. The report calls for the intellectual and operational enhancement of NEHRP through the addition of other relevant federal agencies. The revised program, which would be called the National Earthquake Loss Reduction Program (NEP), would be expected to aggressively pursue a set of well-defined strategic goals outlined in the report. If the recommendations of the report are implemented, they should facilitate program focus, the leveraging of scarce human and financial resources, and increased program coordination and integration.

Earthquake Engineering Research Facilities

My final comment concerns research facilities. Because of their importance for the research enterprise, NSF gives considerable attention to the research physical infrastructure in the U.S. In the earthquake hazard mitigation field, experimental research is needed along with analytical and field investigations, and the former can only be done effectively when there are adequate facilities available to researchers. NSF has provided funds for many of the research facilities used for earthquake engineering research in the U.S. today and for their periodic upgrading. For example, NSF recently supported a major upgrading of the earthquake simulator at the University of California at Berkeley, which is the largest shaking table in the U.S. for testing structural models. This facility, originally constructed in 1972, is available for use by engineers in universities, government agencies, and consulting firms. Its recent upgrading allows the table to be used to apply simulated ground motions simultaneously in two horizontal and vertical directions. The table's range of ground motion parameters has also been increased.

NSF and NIST provided the funding for the recently completed earthquake engineering facilities needs assessment requested by Congress. The Earthquake Engineering Research Institute did a professional job of carrying out this effort, including planning the workshop, assembling expert researchers and practitioners to contribute to the assessment, and preparing the final report, "Assessment of Earthquake Engineering Research and Testing Capabilities in the United States." NSF concurs with the report regarding the continuing importance of experimental earthquake research and the conclusion that, while newer and larger research facilities would benefit the field in significant ways, highest priority should be given to updating and maintaining extant facilities, as was done in the Berkeley case. These facilities have contributed to the development of new structural design approaches such as base isolation systems and improvements in building codes and can be expected to continue to do so in the future if their capabilities are periodically enhanced.

NSF also agrees with the report that the lack of any needed laboratory resources in the U.S. can be partially overcome through cooperation with other countries that have the required facilities, as has been the case in the past. For example, the long-term partnership maintained by the U.S. and Japan in large-scale testing has been mutually beneficial to both countries. Dating back to 1980, joint U.S.-Japan large-scale testing programs have included research on reinforced concrete and steel and masonry buildings. There is every indication that the two countries will continue to pursue collaborative research opportunities in the future. Such research, combined with analytical and field investigations, promise to contribute to more effective earthquake hazard reduction efforts in both countries.

Mr. BAKER. Thank you, Dr. Bordogna. Dr. Wright.

STATEMENT OF DR. RICHARD WRIGHT, DIRECTOR, BUILDING AND FIRE RESEARCH LABORATORY, NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

Mr. WRIGHT. Mr. Chairman, and members, thank you for the opportunity to testify for the National Institute of Standards and Technology on the reauthorization of NEHRP.

In NEHRP, NIST is charged to conduct problem-focused research and development to improve standards, codes and practices for buildings and lifelines. This role complements the roles of the other NEHRP agencies.

We have participated actively with a number of organizations, both in the private sector and in the Federal Government, which need state-of-the-art knowledge and practices in earthquake engineering. These organizations include the Interagency Committee on Seismic Safety and Construction, the Building Seismic Safety Council, the Applied Technology Council, the American Society of Civil Engineers, and the Structural Engineering Association of California.

We are working with these organizations to develop guidance documents for seismic rehabilitation. And, we are collaborating with the U.S. Army Construction Engineering Research Laboratory in research for rehabilitation of buildings.

NIST is collaborating with the private sector, with FEMA and NSF to address the urgent needs in steel frame building design and retro-fit, evidenced by the damage to these buildings during the 1994 Northridge earthquake. We are working with the fire and lifeline communities to reduce losses from fires following an earthquake.

We will collaborate with the private sector and other Federal agencies in implementation of the recently issued "Plan for Developing and Adopting Seismic Design Guidelines and Standards for Lifelines."

Our earthquake engineering research program fills gaps in knowledge that prevent improvements in standards and practices. Our participation in standards development and other collaborations with knowledge users help both to identify critical needs for research and to deliver the research results to practice.

Post earthquake investigations provide one of the most effective means to assess the validity of design and construction practices. Lessons learned from these investigations allow engineers to identify knowledge gaps and plan comprehensive programs to address these gaps.

Since the early 1970's, post-earthquake investigation has been an integral part of our program. We led multiagency Federal teams investigating the performance of buildings and lifelines in the January 1994 Northridge, California earthquake and the January 1995 Kobe, Japan earthquake.

These show great needs for improved practices for the seismic safety of existing buildings in general, for the reduction in property loss as well as collapse of buildings, for the improvement of the performance of lifelines, and for the control of fires following earthquakes. However, the much improved performance of buildings and bridges built, using up-to-date design and construction practices, show the effectiveness of NEHRP in reducing losses.

Recommendations from the recent reauthorizations and experiences in recent damage and earthquakes have led to several policy studies related to NEHRP by the National Economic Council, the Office of Science and Technology Policy, the Office of Technology Assessment, and the Earthquake Engineering Research Institute. NIST has given active support to these studies.

In general, they call for greater emphasis in strengthening seismic design and construction practices, which is the focus of our role, and in promoting their implementation, where we have a supporting role. We note there is a knowledge gap as well as an implementation gap.

We still lack nationally-recognized practices for seismic safety evaluation and strengthening of existing buildings, for evaluation and strengthening of existing lifelines, and for the design and construction of new lifelines. The lack of adequate experimental studies is a cause of the unexpected failures of welded steel frames in the Northridge and Kobe earthquakes. Studies in existing facilities are now addressing these needs.

Incidentally, our own seismic testing facilities are among those in need of upgrading and among those that have not been fully used because of lack of funding for experimental studies.

NIST provides the Chair and Secretariat for the Interagency Committee on Seismic Safety and Construction. This committee consists of the 30 Federal agencies concerned with seismic safety which collaborate to develop and incorporate earthquake hazard reduction measures in their programs.

FEMA provides funding for the Secretariat. These agencies, working together using consensus procedures, drafted the Executive Order for seismic safety of Federal and federally-assisted or regulated new building construction of 1990 and the 1994 Executive Order for seismic safety of existing federally-leased or owned buildings.

ICSSC has developed recommended practices using available voluntary national standards and model building codes for implementation of the Executive Orders. As a result of these efforts, all new Federal and federally-leased or assisted buildings are required to meet up-to-date seismic design and construction standards.

All existing federally-owned or leased buildings undergoing a change of use involving higher seismic risk, major upgrading or known to be of exceptionally high seismic risk are required to be evaluated for seismic safety and retro-fitted if found deficient.

The ICSSC agencies have begun to inventory existing federally-owned and leased buildings to estimate the cost required to bring the entire Federal inventory to an acceptable level of safety.

NIST's research for improvement of standards and practices for buildings and lifelines includes research on structural control; research on the lifeline safety, fire safety, and geotechnical engineering, and research on performance of buildings.

NIST has also led the U.S. side of the U.S./Japan panel on Wind and Seismic Effects since 1969. This panel brings together 16 U.S. agencies and 9 Japanese agencies to collaborate, to learn about earthquake effects, mitigation practices, and implementation mechanisms.

Strong collaborative U.S./Japan research programs have occurred with sponsorship from the National Science Foundation, the Federal Highway Administration, and the Geological Survey, as well as NIST, to exploit opportunities to learn from both U.S. and Japanese earthquakes and to use the research capabilities of both countries in the common interests.

Recommendations important to earthquake risk reduction have been made for soil liquefaction; site amplification of earthquake shaking, and design of concrete, steel, and masonry structures. Ongoing U.S./Japan cooperative research deals with composite structures, with structural control, and with fire safety.

Mr. Chairman, thank you for the opportunity to summarize our work in NEHRP. We are making our best efforts in collaboration with the private sector and other Federal agencies to achieve the vision of NEHRP that earthquakes are inevitable but disasters are not.

I will be happy to respond to questions of the Subcommittee.

[The prepared statement of Dr. Wright follows:]

STATEMENT

Richard N. Wright
Director, Building and Fire Research Laboratory
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

before the

House Committee on Science
Subcommittee on Basic Research
The National Earthquake Hazards Reduction Program
Reauthorization Hearing

October 24, 1995

Table of Contents

Mr. Chairman and members, I appreciate the opportunity to testify for the National Institute of Standards and Technology (NIST) on the reauthorization of the National Earthquake Hazards Reduction Program (NEHRP).

1. Introduction

1.1 Congressional Mandate for NIST

In the National Earthquake Hazards Reduction Program, NIST is charged to conduct problem-focused research and development to improve codes and standards and practices for buildings and lifelines. This role complements the lead agency role of the Federal Emergency Management Agency (FEMA), the applied earth sciences role of the U.S. Geological Survey (USGS) and the engineering and fundamental earth sciences research role of the National Science Foundation (NSF). NIST also chairs and provides technical secretariat support to the Interagency Committee on Seismic Safety in Construction (ICSSC) through which 30 federal agencies concerned for seismic safety collaborate to develop and incorporate earthquake hazard reduction measures in their respective programs.

1.2 Meeting the Mandate

NIST has actively participated with a number of organizations, both in the private sector and in the federal government, which need state-of-the-art knowledge and practices in earthquake engineering. These organizations include ICSSC, Building Seismic Safety Council (BSSC), Applied Technology Council (ATC), American Society of Civil Engineers (ASCE), and the Structural Engineering Association of California (SEAOC). For example, ICSSC is given the responsibility to help implement Executive Order 12699 for new federal buildings and Executive Order 12941 for existing buildings. NIST is participating with ASCE, BSSC, and ATC, to develop design and construction guidance documents for seismic rehabilitation, and collaborating with the U.S. Army Construction Engineering Research Laboratory in supporting research. NIST has also been working with ATC, SEAOC, and the California Universities for Research in Earthquake Engineering (CUREe) to address urgent needs in steel frame building design and retrofit evidenced by the damage to those buildings during the 1994 Northridge earthquake. NIST also is working with the fire and lifeline communities to reduce losses from fires following an earthquake.

NIST's earthquake engineering research program aims at filling gaps in knowledge that prevent improvements in standards and practices. NIST's participation in standards development and other collaborations with knowledge users help both to identify critical needs for research and to deliver results to practice.

Post earthquake investigations provide one of the most effective means to assess the validity of design and construction practices. Lessons learned from these investigations allow engineers to identify knowledge gaps and plan comprehensive research programs to attack those gaps. Since the early 1970s, post-earthquake investigation has been an integral part of NIST's earthquake engineering program.

This testimony covers:

- Post-Northridge Earthquake and Post-Kobe Earthquake Investigations,
- Funding for NIST in NEHRP,
- NIST support of the development of policy recommendations for NEHRP.
- Participation in the management and planning of NEHRP,
- Support for developing and implementing earthquake hazard reduction practices,
- Leadership of the ICSSC in addressing the seismic safety of existing federal buildings in implementation of Executive Order 12941, "Seismic Safety of Existing Federally Owned and Leased Buildings," and of new buildings in implementation of Executive Order 12699, "Seismic Safety of Federal and Federally Assisted or Regulated New Building Construction."
- Problem-focused engineering research addressing needs for improved seismic design and construction practices,
- Participation in technology transfer through standards activities and industry collaboration, and
- International collaborations for earthquake hazard reduction.

The vision of NEHRP is that earthquakes are inevitable natural hazards, but need not be inevitable disasters. In spite of its limited resources in NEHRP, NIST has made substantial contributions to achieving the vision of NEHRP; we look forward to further and accelerated progress.

2. Funding for NIST in NEHRP

NIST's appropriation for NEHRP in Fiscal Year 1995 was $ 1,932,000, but was reduced by rescission to $1,149,000. In addition, NIST was able to use funds from the Northridge Supplemental fund received in Fiscal Year 1994 from Congress and from FEMA for the investigation of the effects of the Northridge earthquake. Additional funding has been provided by other Federal agencies, such as FEMA, for technical support of their programs. Table 1, located at the end of this report, shows NIST's NEHRP funding for Fiscal Years 1993 through 1996.

3. Post-Earthquake Investigations

Two moderate earthquakes, the January 1994 Northridge and January 1995 Hyogo Ken Nanbu (Kobe) earthquakes, which hit urban areas in California and Japan respectively, offered the earthquake engineering community an unprecedented opportunity to assess how the modern built environment responds to such powerful natural forces. In both earthquakes, NIST engineers led multi-agency federal teams to conduct post-earthquake investigations.

3.1 The January 17, 1994 Northridge Earthquake, California

Earthquakes provide a natural laboratory setting that allows us to evaluate not only the performance of the built environment when subjected to strong ground shaking, but also the catastrophic effects which a large earthquake can have on the people who inhabit those structures. Immediately after the January 17, 1994, Northridge earthquake, ICSSC, with NIST leadership, sent a reconnaissance team to the Los Angeles area to conduct observations of components of the built environment, including bridges, buildings, and lifelines such as gas and water systems, as well as to assess the causes of fires. NIST published its reconnaissance report entitled "1994 Northridge Earthquake: Performance of Structures, Lifelines, and Fire Protection Systems" in March 1994; a copy is offered for the record.

This magnitude 6.8 earthquake, which occurred in the San Fernando Valley, resulted in 58 deaths and an estimated total loss of $30 billion. Strong ground shaking caused severe damage to over 11,000 homes, residential buildings, and commercial structures; six major highway structure collapses; and damage to over 150 highway overpasses. In addition, it resulted in the loss of power and water supply to tens of thousands of residents for an extended period of time, as well as fires that destroyed houses and mobile homes in several mobile home parks. However, the much improved performance of buildings and bridges designed and constructed using up to date seismic standards show the effectiveness of NEHRP in reducing losses.

One of the major results of reconnaissance efforts was the discovery of the failure of many welded steel moment frames at welded joints. This behavior was unexpected and had not been observed in previous earthquakes. Joint efforts between NIST and private sector organizations have developed survey and testing programs to determine what caused these failures and how welded steel frames should be repaired, rehabilitated or designed in the future.

3.2 The January 17, 1995 Hyogo Ken Nanbu (Kobe) Earthquake, Japan

Exactly one year after the Northridge Earthquake, the Kobe Earthquake occurred. This earthquake, although of similar magnitude to the Northridge Earthquake, caused much more damage and suffering due to its location directly under a densely populated area, an area like that in many major US cities.

The earthquake was the first time in recent history that a moderate earthquake (magnitude 6.9) devastated a modern urban region. It killed nearly 5,500 people, damaged or destroyed over 150,000 buildings and homes, and disrupted the services of all lifeline systems: transportation, water and sewer, gas and liquid fuels, electric power, telecommunications, and ports and harbors. Fires following the earthquake resulted in the total destruction of areas equivalent to about 70 U.S. city blocks. Japanese authorities estimate the total economic loss to exceed $200 billion dollars.

Under the auspices of the U.S.-Japan Panel on Wind and Seismic Effects, technical experts from federal agencies participated in the post-earthquake investigation immediately after the earthquake to assess the performance of the built environment and to learn to prepare the United States for future earthquakes. Technical areas covered in the investigation included the study of geological and seismological issues, the collection of field data related to them, and the performance of buildings and lifelines.

Many lessons have been learned from this investigation. These include:

- Moderate and large earthquakes directly beneath densely urbanized areas can cause catastrophic loss of life and property. Important factors contributing to these losses are proximity to the earthquake crustal-rupture zone, amplification effects of loose soil deposits, and liquefaction susceptibilities of reclaimed land and loose soil deposits.

- Most of the destroyed homes were non-engineered wood-frame residences of traditional Japanese design built between 1940s and 1970s. The lack of horizontal resistance in their design, coupled with heavy clay tile roofs, resulted in total destruction of many of such buildings. In comparison, U.S. homebuilding technologies performed well in local demonstration projects.

- Many older reinforced concrete buildings also were severely damaged or collapsed. A major revision of the building code in 1981, which significantly upgraded seismic resistance requirements, significantly lessened damage in newer buildings.

- Older steel frame buildings (prior to 1981) suffered damage. Some new steel frame buildings also had unexpected damages, such as brittle failures of steel sections at welds.

- It appears that the eastern and central U.S. may have more than California to learn from this earthquake in Japan because of the predominance of steel girder bridges used in these regions. Some of these lessons are:
  - The closure of arterial highways affects emergency relief and business recovery and can have a major economic impact on a region.
  - Capacity design procedures, ductile details and generous seat widths are necessary to prevent catastrophic collapse during large earthquakes.
  - Minimum connection forces need to be enforced for all seismic zones unless connections can be shown to be fully protected by acceptable yielding of the main members. Redundancy in connection detailing is particularly important for essential structures.
  - Critically important structures must be designed to a higher level of performance.
  - Retrofit measures reduce damage but inappropriate use and/or installation can defeat their purpose and perhaps even trigger collapse.

- Lateral spreading due to liquefaction can lead to collapse even in modern structures.
- Skewed bridges are susceptible to in-plane rotation leading to large displacements at their supports and possible unseating of girders in the acute corners.

- Rail services suffered more damage along the elevated structure sections than along the elevated embankment sections. Damage to reinforced concrete structures (columns) was extensive; the major cause of collapses was the non-ductile detailing of the steel reinforcement. Structures designed by current specifications performed well with minor damage.

- The extensive damage to the port of Kobe highlights the seismic hazard of loose sandy fills. Such materials have been widely used in the United States and worldwide to reclaim ground for port development and expansion. The earthquake once again demonstrated that these fills liquefy and generate large permanent ground displacements.

- There is a need to focus on the issue of fire following earthquakes. In Kobe, while there was no fire storm, there were 380 ignitions, and often no water to suppress them. Water purveyors and fire departments should review the vulnerability of water supplies. Recent earthquakes have shown that there is a low probability of maintaining a water system following an earthquake unless systems are designed and constructed, or retrofitted, for earthquake resistance. Consideration should be given to identifying and developing alternate supplies. Similarly, the use of monitoring and control systems should be considered to enable timely cutoff of a broken water system to save water in reservoirs for subsequent fire fighting.

- An important lesson learned from this earthquake is the need to coordinate the restoration of electric power with an assessment of the state of gas system repair. It appears that premature restoration of electric power in areas of Kobe with leaking gas contributed to additional fires.

- The difficulty and substantial time required for restoration of gas service in Kobe is an important reminder of the complexities and resources required for the resumption of gas supply after large-area shutdowns. Restoration of gas can be especially critical in U.S. areas with cold winter weather. It may be advantageous to provide for remote control and other rapid means of isolation of smaller, more manageable areas of the gas system.

- The extensive damage to vulnerable piping is a very important lesson and a sobering reminder of potential earthquake effects on weak systems. Although threaded steel piping is used rarely in U.S. gas systems, many U.S. systems do use cast iron mains, which are vulnerable to earthquakes, for low pressure distribution.

- High voltage bushings in electrical substations appear to contribute to poor seismic performance both in US. and Japan. Also, at potentially liquefiable sites, the need was shown for adequate slack in electrical wiring and in piping.

- Communication facilities are vulnerable to loss of water and emergency power.

- Passive fire protection systems were effective in stopping fire spread. A major earthquake overwhelms the capabilities of fire departments and public service rescue organizations. Homeowner self-help needs to be part of disaster response.

4. Policy Recommendations

The losses suffered in the Northridge earthquake and in recent hurricanes have resulted in an increased scrutiny by the federal government of its policies and activities for natural hazards reduction. This scrutiny has led to the FEMA-led development of the National Mitigation Strategy and to the recent publication of several studies by various government and private sector organizations which focus on needs for federal earthquake disaster mitigation and relief programs. In general, these studies recommend an increased emphasis on the mitigation of existing structures and lifelines which are vulnerable to earthquakes, increased research in areas of rehabilitation, increased sharing and utilization of this research, a larger education program to increase awareness of mitigation in the public, and the increased utilization of insurance industry policies to help promote mitigation.

NIST has contributed to these studies and is prepared to participate in implementation of their recommendations to the extent of resource availability.

4.1 Administration Policy Proposals

Administration Policy Proposals on Natural Disaster Insurance and Related Issues, submitted by the Department of the Treasury and FEMA on February 16, 1995, discussed "the growing concern that the costs of natural disasters - in terms of lives lost, property damaged, and economic dislocation - are simply too high, both to society as a whole and to the Federal government." These proposals emphasize cost-effective mitigation actions to reduce losses, and make mitigation a requirement for insurance against catastrophic events, and for post-disaster relief.

4.2 Office of Science and Technology Report

The "Strategy for National Earthquake Loss Reduction" was completed recently by the National Earthquake Strategy Working Group for the Office of Science and Technology Policy (OSTP). This study recommends a new National Earthquake Loss Reduction Program (NEP) which would strengthen and extend the existing NEHRP. The new program would emphasize: utilization of agencies beyond the four NEHRP agencies, an increased emphasis on loss prevention and mitigation, the further development of technology transfer with the private sector and the establishment of education programs for earthquake loss reduction.

4.3 Office of Technology Assessment Report

The Office of Technology Assessment's recently published report "Reducing Earthquake Losses", is in agreement that "damaging earthquakes will strike the US in the next few decades, causing at the minimum dozens of deaths and tens of billions of dollars in losses." This report states that "NEHRP has led to significant advances in our knowledge of both earth science and engineering aspects of earthquake risk reduction" and it recommends expanding the current scope of the NEHRP program to increase research on the retrofit of existing structures, to provide more direct support for public implementation programs, and to provide incentives for mitigation by making it a condition for federal disaster assistance. It should be noted that the federal government has shown leadership in requiring use of up-to-date seismic design and construction practices for new federal and federally-assisted buildings, including, for instance, new homes to be financed by VA. Also, there is a knowledge gap as well as an implementation gap. We lack nationally recognized practices for seismic safety evaluation and strengthening of existing buildings, and for the evaluation and strengthening of existing lifelines or the design and construction of new lifelines.

4.4 Lifelines Plan

Lifelines are the public works and utility systems that support most human activities, and also are vulnerable to earthquakes. A Plan for Developing and Adopting Seismic Design Guidelines and Standards for Lifelines has been prepared by FEMA, in consultation with NIST and the private sector, in response to Public Law 101-614, the NEHRP Reauthorization Act. The Plan focuses on developing guidelines for existing and new lifelines, testing the guidelines in trial applications, making improvements, encouraging and supporting the adoption of these recommendations by the standards and professional organizations serving the lifelines community, and working with the lifeline community to achieve their effective implementation. Like those reports mentioned above, the Plan emphasizes efficient management, close coordination between the public and private sectors and the development of implementation and education efforts. NIST looks forward to carrying out its assignment in the Plan.

4.5 Research and Testing Capabilities Needs Assessment - EERI

A report entitled "Assessment of Earthquake Engineering Research and Testing Capabilities in the United States" was completed by the Earthquake Engineering Research Institute (EERI) in response to Public Law 103-374. This report states that significant reduction in economic and other losses from future earthquakes in the United States can be realized through an accelerated and coordinated national program of earthquake engineering research and testing. The direct benefits of such a program include the improved knowledge of the complex phenomena controlling seismic performance of structures and lifelines, the rapid development of reliable design guidelines and standards, and the development of a technically sound basis for actions and policy decisions by government leaders, insurance brokers, owners and others. The report recommends that existing testing facilities be upgraded and used in an augmented program of experimental and analytical studies to provide bases for improved loss reduction practices.

We note that the lack of adequate experimental studies is a cause of the unexpected failures of welded steel frames in the Northridge and Kobe earthquakes, and that studies in existing facilities are addressing these needs. NIST's seismic testing facilities are among those in need of upgrading, and among those that have not been fully used because of lack of funding for experimental studies.

5. NIST Role in NEHRP Management and Planning

Despite its severely limited resources in NEHRP, NIST has contributed equivalently to the other principal NEHRP agencies in the management and planning of NEHRP.

I have represented NIST in the NEHRP Interagency Coordinating Committee (ICC), whose members are the senior line managers of the principal agencies. ICC provides policy-level direction in the preparation of the coordinated and consolidated budget for NEHRP and its presentation to the Office of Management and Budget, the development of the Five Year Plan for NEHRP, and in strategic planning. ICC also coordinates the execution of the NEHRP program including: preparation of Congressionally-mandated studies, collaborations with private and public sector elements of the earthquake community, and development of the biennial NEHRP report to Congress.

6. Development and Implementation of Earthquake Hazard Reduction Practices Through the ICSSC

In accord with P.L. 101-614, NIST provides the chairman and technical secretariat for the Interagency Committee on Seismic Safety in Construction (ICSSC), through which 30 Federal agencies concerned for seismic safety collaborate, to develop and incorporate earthquake hazard reduction measures in their programs. FEMA funds the work of the ICSSC secretariat. To link its activities to those of the private sector, the ICSSC chairman serves as a member of the Board of the Building Seismic Safety Council (BSSC), and ICSSC members serve on many technical committees of BSSC.

6.1 Implementation of Executive Order 12699

Following the President's issuance of Executive Order 12699, "Seismic Safety of Federal and Federally Assisted or Regulated New Building Construction," in January 1990, NIST and ICSSC undertook a number of activities in support of the Executive Order's implementation. These included translating the "NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings" into language suitable for incorporation into the national buildings codes, issuing a recommendation that the seismic provisions of the then current editions of the three model building codes are appropriate for implementing the Executive Order, and developing "Guidelines and Procedures for Implementation of the Executive Order on Seismic Safety of New Building Construction" to assist the agencies in developing their programs in response to the Executive Order.

The ICSSC continues in its efforts to promote the Executive Order and to assist agencies in developing their specific programs. In May 1995, a report was issued which compared the most recent editions of the ICBO Uniform Building Code, the BOCA National Building Code, the SBCCI Standard Building Code, the CABO One and Two Family Dwelling Code, and ASCE 7-93, "Minimum Design Loads for Buildings and Other Structures" to the 1991 edition of the NEHRP Recommended Provisions. Also in May 1995, the ICSSC issued a recommendation, based on the results of this study, which stated that the seismic provisions of the current editions of the three model building codes, as well as ASCE 7-93 and Appendix, are appropriate for implementing the Executive Order. This recommendation is very important for cost-effective seismic safety. The designer of a federal, or federally-assisted or regulated building, can use the model building code familiar to the locality without incurring either the expense or the possibility of misunderstanding involved with use of an unfamiliar special federal seismic requirement.

6.2 Implementation of Executive Order 12941

Damage from recent earthquakes has made it apparent that existing structures built before the use of modern seismic codes are at much higher risk during an earthquake. However, there previously have been few requirements to upgrade any of these buildings and there have been no building codes or standards for the rehabilitation of these buildings. The federal government, using the ICSSC, has taken a lead role in the recognition of this problem and the development of the tools to tackle it. Public Law 101-614 called for the ICSSC to work with appropriate private sector organizations in the development of standards for assessing and enhancing the seismic safety of existing buildings constructed for or leased by the federal government. The standard, RP-4, "Standards of Seismic Safety for Existing Federally Owned or Leased Buildings", was published in February 1994. The Law also called for the President to adopt the standards by December 1, 1994. Executive Order 12941, "Seismic Safety of Existing Federally Leased or Owned Buildings" was drafted by ICSSC and signed by the President on December 1, 1994. This Executive Order is the implementing authority for the RP-4 Standard and requires all federal agencies to use the RP-4 Standard as a minimum when evaluating or rehabilitating existing buildings for seismic safety.

RP-4 describes certain trigger situations which require an agency to evaluate and develop a plan for the mitigation of any building found to be seismically deficient. These triggers include a change in the use of the building, other upgrades being performed on the building, and the determination of the building as representing an "exceptionally high seismic risk." This provides an initial effort to reduce the seismic risk in federal buildings. In order to determine the full extent of the level of seismic risk in existing federal buildings, a more extensive program must be put into place. For this reason, Executive Order 12941 tasks all affected federal agencies to develop a full inventory of their owned and leased buildings, and to develop estimates of the costs expected to bring this inventory up to a level of acceptable seismic safety. The information collected through this effort will be used to develop recommendations for an economically feasible plan to mitigate earthquake risks in existing federal buildings.

The Executive Order states that the details for the inventorying and cost estimating effort are to be published by the ICSSC within one year of the signing of the Order. In response, the ICSSC is developing two documents. The Guidance Document provides the recommended methodology for collecting and reporting inventory and cost estimate information. It was approved by the ICSSC on October 3, 1995. The Handbook suggests detailed techniques for developing this information. Both documents are slated for publication before December 1, 1995.

6.3 Technical Support to FEMA/BSSC

In addition to its support of the ICSSC, NIST also provides technical expertise to assist FEMA in the review of projects to develop design and construction guidance documents for seismic rehabilitation. This includes the technical review of the "Guidelines for Seismic Rehabilitation". This project, which is being developed by the BSSC, Applied Technology Council (ATC), and the American Society of Civil Engineers (ASCE), is a multi-year effort to develop comprehensive guidelines for the seismic rehabilitation of existing buildings. This type of comprehensive guidance currently does not exist, hence the document will provide an extremely useful tool to promote the cost-effective rehabilitation of seismically vulnerable buildings. By providing technical assistance on this and similar projects, NIST is able to provide a link between the development of federal and private sector seismic rehabilitation guidelines. The project is scheduled for completion in 1997.

NIST is also involved in the technical review of an update of the FEMA document, "Typical Costs of Seismic Rehabilitation of Buildings." This project has produced two volumes which can be used to establish an estimate of the costs to rehabilitate specific types of existing buildings. This product will be extremely useful in the cost-estimating efforts required by Executive Order 12941.

7. Earthquake Engineering Research Activities

NIST's earthquake engineering research activities focus on three major program areas: 1) structural control, 2) lifeline and geotechnical engineering, and 3) strengthening of existing structures and improvement of new structures. These program areas were selected through the collaborations with users described in Section 1 to make best use of the resources provided to NIST through NEHRP.

NIST's earthquake engineering research activities were recently supported through two distinct funding sources: the normal year funding through NEHRP appropriation and the emergency appropriation resulting from the January 17, 1994 Northridge earthquake in southern California.

The support from both funding sources allowed NIST to support studies of critical issues related to fires following earthquakes and the performance of steel frame buildings to expand its collaborative efforts with many other organizations in the nation's earthquake hazard mitigation community.

7.1 Structural Control

In its natural progression, the subject of structural control may be divided into three phases: seismic isolation (base isolation), passive energy dissipation, and active (or hybrid) control. Structural control is planned as a multi-year program in which NIST will develop test methods for structural control devices and systems in order to assist in bringing innovations into practice. NIST's current effort is focusing on the seismic isolation technology. Future efforts will address technical issues in the areas of passive/active/hybrid control systems.

Performance Requirements for Seismic Isolation Systems

Seismic isolation has been demonstrated in recent earthquakes as an effective means for reducing the level of response in structures during strong earthquake ground shaking. Testing of the isolation system prior to installation is required by each of the existing building codes that deal with the design of isolated structures; however, standards do not yet exist for conducting these much needed tests, and therefore, procedures and results are subject to considerable variability. NIST has completed the development of draft guidelines, a pre-standard, for testing of isolation systems. The guidelines address pre-qualification, prototype and quality control testing. The guidelines were developed in collaboration with an oversight committee and with inputs from about 40 workshop participants. Work is continuing to develop a detailed experimental and testing plan, to conduct tests according to the procedures established in the Draft Guidelines, and to report on the adequacy and feasibility of the guideline test procedures based on the observations and experience gained in the test program.

NIST's guidelines are being used to evaluate innovative base isolation systems for highway structures. NIST also has proposed to ASCE that the NIST guidelines be used as the basis for developing an American National Standard Institute (ANSI) national consensus standard for testing of base isolation systems. ASCE has formed a standard committee and NIST serves as the committee's technical secretariat. This is an example of technology developed at NIST being transferred into engineering practice.

7.2 Lifeline and Geotechnical Earthquake Engineering

The objective of the NIST's lifeline and geotechnical earthquake engineering program is to develop the knowledge base, through appropriate research, that is needed to support the development of design guidelines, as proposed in the Plan for Developing and Adopting Seismic Guidelines and Standards for Lifelines.

Lifeline systems, i.e., water supply and sewers, gas and liquid fuels, electric power, transportation, and telecommunication systems, are public works and utilities systems that support most human activities: individual, family, economic, political, and cultural. Disruption in services of lifelines can be devastating, as demonstrated by the aftermath of the Northridge and Kobe earthquakes. In the past few years, NIST's lifeline program has concentrated its effort on technical topics common to all lifelines, such as determination of soil liquefaction potential, and assessment and development of methods to improve soil deposits to reduce or eliminate liquefaction potential.

Fires following earthquakes are another major hazard, particularly in urban settings such as Kobe and many major cities located in seismic regions in the United States. Failures of lifelines, such as natural gas, electric power, and water supply, both cause fires and inhibit their suppression. The Northridge Earthquake Supplemental Fund has allowed NIST, with the fire and lifeline communities, to examine a number of critical issues related to fire/lifelines.

Estimating In-Situ Liquefaction Potential and Assessment of Ground Improvement Technologies

In-situ methods are preferred since it is impossible to test in the laboratory "undisturbed" samples of loose soil deposits, which are most susceptible to liquefaction. The state of practice is the Standard Penetration Test (SPT) based method. The Spectral Analysis of Surface Wave technique has potential for examining the large areal extent of lifeline routes. Its effectiveness is being evaluated.

Numerous techniques have been developed for improving loose soil deposits to reduce or eliminate their liquefaction potential. All these methods were developed through empirical approaches. They are generally costly. Moreover, not all of them are appropriate for use in retrofitting or strengthening existing lifelines. A second task of this study is to assess the effectiveness of various methods and recommend their proper use. A report entitled "Ground Improvement Techniques for Liquefaction Remediation near Existing Lifelines" has just been published.

Fire/Lifelines Workshop

The workshop was held in January 1995 in Long Beach, California to identify research needs related to fire ignition and suppression and the performance of related lifeline systems. The objective of the workshop was to identify technology development and research needs for reducing the number and severity of post-earthquake fires. Forty-two experts from fire and lifeline communities participated in the workshop to develop a priority list of 20 topics. Many of the topics are being addressed through grants to conduct the needed studies. They include:

Northridge Post-Earthquake Monograph on Lifeline Performance NIST has engaged the American Society of Civil Engineers' Technical Council on Lifeline Earthquake Engineering (TCLEE) to conduct a follow-up lifeline investigation of the earthquake and publish a monograph of the observations and lessons learned. The monograph was published in August 1995, presenting the information collected in the initial investigation conducted immediately after the earthquake, as well as the follow-up visits to the damaged sites in the months leading to the publication.

Protection of Building Envelope from External Fire Sources This study evaluates the fire exposure conditions that cause glass to fall, examine the protection afforded by strategies that could easily be retrofitted, and address the protection of soffit vents from external fire penetration in single family homes.

Fire-Related Aspects of the Northridge Earthquake This study investigates and fully documents fires, fire spread and fire department operations; provides analysis of this data in support of future estimation of fires following earthquakes; and summarizes lessons learned and insights resulting from this earthquake, in support of loss reduction practices and mitigation of potential conflagrations and large loss of fires following earthquakes.

Analysis of Fire Sprinkler System Performance in the Northridge Earthquake The study will analyze the performance of fire sprinkler systems in the earthquake in relation to the specific earthquake protection measures employed in their design and installation, and develop proposed changes to the national installation standard, NFPA 13, to improve future system performance by bringing brace fastener details up to current levels of technology.

Fire Hazards and Mitigation Measures Associated with Seismic Damage of Water-Heaters and Related Components The study aims to assess seismic damage of nonstructural elements in buildings which may lead to fire hazards; review current codes and provisions related to seismic design of water heaters and related components, develop, through analysis and experiments, mitigation measures which can be effective in minimizing fire hazards; and recommend specific code provisions and design guidelines for this class of nonstructural components.

Evaluation of Passive Fire Protection Systems Following Earthquakes This effort seeks to create a post-earthquake safety evaluation of the passive fire prevention features of buildings and add such evaluation to the ATC-20 document, "Procedures for Post-earthquake Safety Evaluation of Buildings," which in its current form lacks procedures for fire protection system evaluation.

Reliability and Restoration of Water Supply Systems Following Earthquakes The study will assess post-earthquake system reliability and make recommendations to enhance post-earthquake operability of domestic water supply and/or alternate water supply systems, and enable quick restoration of service following an earthquake.

Seismic Risk Assessment of Liquid Fuel Systems This study will review and integrate available methods and procedures of seismic risk assessment and loss estimation, develop a framework for risk assessment that can logically accommodate the state-of-the-art results of research and development efforts on the physical and functional performance of the liquid fuel transmission systems subjected to earthquakes, identify and highlight the design issues that must reflect the risk concept in the process of the development of design guides, and develop and draft an outline of design guides.

Seismic Performance of Liquid Fuel Tanks This study will document and evaluate the performance of liquid fuel tanks during the past and most recent major earthquakes, particularly the Northridge and Kobe earthquakes, assess their performance with respect to the current design and construction practices, and develop recommendations for improving their future performance.

7.3 Strengthening of Existing Structures and Improvement of New Structure Design

Post-earthquake investigation efforts following the Northridge and Kobe earthquakes again demonstrated the much higher vulnerability of older buildings designed and constructed using outdated methodologies and technologies. This observation further highlights the urgency to focus the engineering community's effort to develop methods for strengthening or retrofitting existing buildings and structures. Development of the best and most cost-effective strengthening techniques for different types of buildings and structures has been one of NIST's major thrusts in the past several years.

There also is need to improve methods for the design and construction of new buildings and structures. This includes the use of new materials and systems for seismic resistant design and the ability to develop good detailing of structural components to improve their ductility when subject to seismic loading.

Projects in this program area are:

Performance of Welded Steel Moment Frame Structures

Welded steel moment frame (WSMF) buildings have long been considered to be much less vulnerable to sustaining serious damage under strong ground shaking when compared with other types of buildings. However, after the Northridge earthquake, engineers uncovered wide-spread evidence of fractures in steel members and welded joints of WSMF buildings. The situation is so serious that the State of California issued an unprecedented advisory urging owners whose buildings suffered cosmetic damage to conduct thorough inspections to ensure that building damages were indeed only cosmetic. To assure safe and reliable seismic performance of WSMF structures in future earthquakes, the following tasks must be accomplished:

- Characterize and understand the nature of the failures.

- Prepare interim procedures to identify buildings which may have been damaged, establish the condition of damaged buildings, and rehabilitate the damaged buildings.

- Prepare recommendations for the repair, retrofit and design of WSMF buildings based on a rational understanding of seismic behavior.

NIST is an active participant in the SAC (SEAOC, ATC, and CUREe) effort established after the Northridge earthquake to address critical issues, both in retrofit and new design of steel frame buildings. NIST-sponsored efforts, which are underway as part of a comprehensive program to accomplish these tasks, include the following:

a. Workshop on Seismic Performance of Steel Frame Buildings The purpose of this workshop was to bring together experts from across the country to form a national perspective on the problems observed in the performance of WSMF buildings in the Northridge earthquake and to develop a research plan and determine the best approach for solving these problems. Proceedings of this workshop were published in November 1994.

b. Performance of Steel Frame Buildings During the 1994 Northridge Earthquake This project consisted of developing and performing a detailed survey of those WSMF buildings which were damaged in the Northridge earthquake. This survey provided a basis for establishing the extent of the problem and determining the best course of action to address the research and analytical aspects of the program. The report from this effort was published in April 1995.

c. Enhancement of IDARC Program for Modeling Inelastic Behavior of Welded Connections in Steel Moment Frame Buildings The purpose of this project is to modify an existing program which models the inelastic behavior of reinforced concrete structures for use in modeling the WSMF connections damaged in the Northridge earthquake. The modified program was published in April 1995.

d. Failure Analysis of Buildings Structural Damage Sustained in the Northridge Earthquake The objective of this project is to identify, document and arrange for removal of actual failed sections of beam-column connections and to use these connections to characterize properties of the beam and column flanges, properties of the weld metal and heat-affected-zones, and fracture origin and mechanism, and to evaluate the test results to understand the causes of failures.

e. Detailed Investigations and Analysis of Two Steel Frame Buildings Which Suffered Extensive Damage in the 1994 Northridge Earthquake This project examines and fully documents the damaged condition of selected buildings and conducts analyses of the building systems using various types of analytical tools to assess the ability of these tools to predict the observed damage.

f. Computer Modeling for Analysis of the Performance of Steel Buildings The objective of this project is to develop modeling assumptions and computer models for analyzing three WSMF buildings, varying from 4 to 6 stories, which suffered extensive damage in the Northridge earthquake.

g. Large Scale Testing of Retrofitted Steel Moment Connections There are currently three projects underway at three universities to test retrofit schemes for the types of connections which failed in the Northridge earthquake. These projects will test the effectiveness of three schemes and develop important data needed to formulate design guidance for these retrofit schemes.

Seismic Performance of Precast Concrete Connections

The objective of this project is to develop building code provisions for moment resistant precast concrete beam-column connections. These are based on design guidelines derived from experimental work jointly sponsored by NIST and the private sector and completed at NIST. Proposed revisions to building codes require careful attention to exact content and wording so as to avoid conflicts with existing code requirements, the unintentional exclusion of materials and/or procedures, and potential mistakes caused by misinterpretation of the proposed changes. The inclusion of the guidelines into national building codes is an important step in the implementation of research results. NIST-developed design guidelines have been presented to SEAOC and the American Concrete Institute committees for their consideration for adoption into building codes and standards. Such adoption would allow the introduction of this new form of connection in new construction to gain the advantages of pre-cast construction with seismic safety. This is another example that technology developed at NIST is being transferred into engineering practice.

Seismic Resistance of Partially Grouted Reinforced Masonry Walls

Results available from U.S. and foreign tests of fully- and partially-reinforced masonry shear walls have been compared to predictive equations for the ultimate flexural and shear resistance. Partially-grouted masonry, in which vertical reinforcement is concentrated in a few cells and only those vertical cells containing reinforcement are grouted, promises to be a cost-effective measure for construction of masonry buildings in moderately seismic regions, such as regions east of the Rockies. The Council for Masonry Research also has suggested that NIST investigate the replacement of bond beams, which contain the horizontal reinforcement needed to resist horizontal shear forces generated by the seismic motions, with bed joint reinforcement, which are electrically-welded grids of reinforcing wire. This replacement also has a high potential for improving the productivity and enhancing the cost-effectiveness of the U.S. masonry construction industry. NIST has developed a detailed plan for a comprehensive, multi-year experimental and analytical investigation on the shear strength of partially-grouted masonry shear walls. The experimental data is needed to calibrate an empirical expression developed by NIST staff for predicting the shear strength of partially-grouted masonry walls, as well as to verify existing finite element model of masonry shear walls.

Seismic Performance of Cladding Systems

This study is to evaluate the seismic performance of exterior architectural cladding elements during the Northridge earthquake, and to develop energy dissipating cladding systems for seismic retrofit and design of new buildings. Although cladding elements are not specifically designed for seismic forces, they participate in resisting lateral loads as they deform with the framing system. Some cladding systems sustained damage during the Northridge earthquake, particularly those on steel frame structures. The seismic performance of buildings could be improved by utilizing effectively the cladding system to dissipate energy and these systems can conceivably be applied to both new construction and seismic retrofit. The end result of this effort will be seismic design guidelines for building cladding systems.

Performance of Non-Structural Components

This study is to develop recommended provisions for the seismic design of non-structural components in buildings. Non-structural components include such elements as suspended ceilings, exterior cladding panels, water pipes, ventilating ducts, window glass, furniture, and mechanical equipment. Damage to non-structural components in earthquakes often costs as much as damage to the structure itself. Current practices for seismic design of non-structural components are being evaluated. A detailed study of critical non-structural components will follow to develop recommended provisions for seismic design of non-structural components.

Performance of Rehabilitated Masonry Buildings and Development of Performance-Based Rehabilitation Guidelines

Despite the rehabilitation requirements in Los Angeles, many rehabilitated unreinforced masonry (URM) buildings were badly damaged during the Northridge earthquake. As a life-safety measure, current rehabilitation practices appear to be successful. However, rehabilitation was not successful in reducing property damages, which often led to significant cost for repair and associated business disruption. This study is to document the performance of rehabilitated URM buildings, evaluate the effectiveness of current rehabilitation practices, and develop guidelines for rehabilitation achieving both life safety and property loss reduction.

Seismic Strengthening Methodologies for Existing Lightly RC Frame Buildings

The objective of this effort is to contribute to the current development of rehabilitation design guidelines for existing lightly reinforced concrete (RC) frame buildings by translating existing and new research results obtained in NIST research efforts into technology usable by designers. A recently completed NIST program on strengthening lightly RC frame buildings with infill walls produced a set of design considerations. Design charts and procedures, tables, and simplified equations will be developed to convert the research tools into practical tools and technologies to support performance-based design approaches. The work from this project also will support the development of the FEMA guidelines for seismic rehabilitation.

Inelastic Damage Model for Rectangular Reinforced Concrete Columns

With the co-sponsorship of the Federal Highway Administration, State of California's Department of Transportation, and National Center for Earthquake Engineering Research, NIST is continuing its effort in developing new and innovative methods to improve the seismic performance of reinforced concrete bridge columns. Several computer-based analysis models which predict the dynamic performance of reinforced concrete structures in earthquakes in both the elastic and inelastic range of behavior are currently available. However, inelastic models remain theoretical tools which cannot be used with confidence until they are systematically calibrated against laboratory test data. This project will demonstrate a calibration procedure for the program IDARC which could be adapted for use with other inelastic dynamic analysis software. A digital database of cyclic lateral load tests on rectangular RC columns developed in a previous phase of this project will be used.

Cyclic Lateral Load Tests of Circular Reinforced Concrete Bridge Columns

In earthquake engineering studies of reinforced concrete columns, a controlled, cyclic load pattern with gradually increasing amplitude has traditionally been applied to columns tested in the laboratory. However, in an actual earthquake, a bridge column is exposed to a random cyclic loading pattern, which is much different from the laboratory loading pattern. The differences between these types of loadings have never been explored systematically. In this study both types of loading - controlled, cyclic lateral loads, and random earthquake type loads - will be applied to nominally identical columns and the differences in observed damage will be studied. Recommendations will be formulated for test procedures.

8. Technology Transfer

8.1 Standards Activities

NIST participates actively in over 100 national and international standards development activities for construction and fire. NIST also provides volunteer leadership to major standards organizations such as the International Standards Organization, the American Society for Testing and Materials, the American Concrete Institute (ACI), the American Institute of Steel Construction (AISC), the American Society of Civil Engineers (ASCE), and the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE). Examples of NIST staff's participation relevant to the earthquake engineering program are:

- Dr. H. S. Lew, Chief, Structures Division/BFRL, serves on ACI Committee 318, Standard Building Codes and AISC Specification Committee on Steel Construction

- Dr. Richard Marshall, Leader, Structures Evaluation Group, Structures Division/BFRL, serves on ASCE 7, Wind Loads Task Committee and ASCE Executive Committee of Structural Standards Division

- Dr. Riley M. Chung, Leader, Earthquake Engineering Group, Structures Division/BFRL, serves on ASCE Committee on Natural Disaster Reduction, as vice chair of ASCE

Organizing Committee for the 1996 International Conference on Natural Disaster Reduction, and as chair of Special Session on Lifelines at the 11th World Conference on Earthquake Engineering, June 1996.

8.2 Industry Collaboration

NEHRP depends strongly on professional and industry associations in the U.S. for development of, education in, and implementation of earthquake hazard reduction practices. NIST has been successful in encouraging collaborative activities, and participating in and leading the work of collaborating organizations.

Most recently, efforts to research the extent of the steel moment frame connection failures in the Northridge earthquake have provided an opportunity for NIST to collaborate with private sector organizations such as SEAOC, ATC and CUREe as well as several Universities and private sector companies to work towards design and rehabilitation solutions for the entire building community. The need to examine technical issues related to fires following earthquakes also allowed NIST to collaborate closely with experts from the fire and lifelines communities.

9. International Activities

The NEHRP gains greatly from international collaborations in learning about earthquake effects, mitigation practices and implementation mechanisms. NIST has been active in supporting information exchange through the following international organizations:

- U.S.-Japan Panel on Wind and Seismic Effects includes 16 U.S. Federal agencies and 9 Japanese agencies. NIST provides the U.S-side chairman. The Panel has:
    - held 27 annual technical meetings for prompt exchange of research findings,
    - conducted over 40 workshops and conferences, on topics such as repair and retrofit of structures, involving leading U.S. and Japanese researchers and practitioners,
    - conducted cooperative post earthquake investigations,

- hosted visiting Japanese researchers and provided access for U.S. researchers to unique Japanese facilities,

- organized cooperative research programs on steel, concrete, masonry and precast concrete structures, and

- cooperated in investigations of damaging earthquakes in Japan and U.S.

- International Council on Building Research, Studies and Documentation (CIB). NIST provided the President from 1983-86 and serves on its Board and Program Committee. CIB provides recommendations for international standards on structural resistance to earthquakes and international cooperation on earthquake hazard reduction.

- International Union of Laboratories for Testing and Research on Materials and Structures (RILEM). NIST provided the president from 1982-85, and provides continuing leadership in development of its technical programs.

Table 1

NIST Funding for NEHRP
($ million)

	FY93	FY94	FY95	FY96[1]
NIST Appropriation	1.332	1.532	1.149[2]	1.932
Northridge Supplemental Appropriation: NIST	0	3.000	0	0
Northridge Supplemental Appropriation: FEMA	0	1.500	0	0
Other FEMA (Obligations)	0.244	0.210	0.268	0.240
Other Federal Agencies (Obligations)	0.099	0.103	0.208	0.115
Private Sector (Obligations)	0.154	0.036	0.013	0.050
Total	1.829	6.381		2.337

1 Estimated.
2 Reflects rescission

National Institute of Standards and Technology
Building and Fire Research Laboratory
Structures Division
Earthquake Engineering Publications
(FY93-FY95)

Technology transfer takes various forms and plays a critical role in successfully meeting the NEHRP goals and takes various forms. These forms include publication of problem-focused engineering research results in NIST interim reports (NISTIR); in journals, and conference and workshop proceedings; in trade associations, professional societies, and agencies' newsletters; and through speeches given at professional gatherings.

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RICHARD N. WRIGHT

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His professional experience includes: junior engineer with the Pennsylvania Railroad, 1953 to 1955; Instructor, assistant professor, associate professor and professor of civil engineering at the University of Illinois at Urbana from 1957 to 1974; and at the National Institute of Standards and Technology, Chief of the Structures Section, Building Research Division 1971 to 1972; Deputy Director-Technical, Center for Building Technology, 1972 to 1973; Director, Center for Building Technology 1974 to 1990; and Director, Building and Fire Research Laboratory 1991 to date.

The Building and Fire Research Laboratory (BFRL) is the national laboratory dedicated to the life cycle quality of constructed facilities. It enhances the competitiveness of U.S. industry and public safety through performance prediction and measurement technologies and technical advances that improve the life cycle quality of constructed facilities. It performs and supports laboratory, field and analytical research on the performance of construction materials, components, systems and practices, and the fundamental processes underlying initiation, propagation and suppression of fires. It does not promulgate building or fire safety standards or regulations, but its research results are widely used in these communities and adopted by governmental and private sector organizations with standards and codes responsibilities. It conducts programs in fire research mandated by the Federal Fire Prevention and Control Act of 1974, research and development to improve building codes and standards and practices for buildings and lifelines assigned by the Earthquake Hazards Reduction Act of 1977 as amended, and structural failure investigations mandated by the NBS Authorizing Act for FY 1986.

Dr. Wright has published over 100 articles on building and fire research, computer-integrated construction, formulation and expression of standards, performance of structures, structural design methods for earthquakes and other dynamic loads, flow and fracture in structural metals and mechanics of thin-walled beam structures.

He is Co-chairman of the Subcommittee on Construction and Building of the National Science and Technology Council; Chairman of the Interagency Committee on Seismic Safety in Construction; U.S. Chairman of the U.S.-Japan Panel on Wind and Seismic Effects; Past President of the International Council for Building Research, Studies and Documentation; fellow of the American Society of Civil Engineers and the American Association for Advancement of Science; and member of the Earthquake Engineering Research Institute, National Society of Professional Engineers, Sigma Xi, Phi Kappa Phi, and Tau Beta Pi. He registered as a professional engineer in New York in 1958 and as a structural engineer in Illinois in 1974.

He received the Gold Medal Award of the Department of Commerce in 1982 for distinguished achievement in the Federal Service, was selected for the Rank of Meritorious Executive by the President in 1988; received the Special Presidential Award of the Illuminating Engineering Society of North America in 1983 for contributions to the organization of the Lighting Research Institute; and was named Federal Engineer of the Year 1988 by the National Society of Professional Engineers.

Mr. BAKER. Thank you very much, Dr. Wright. The OTA report found a lack of quantitative data, both in losses before mitigating and losses after we would mitigate an area for higher building standards.

Do you have anything to say about what NEHRP can do about this?

Mr. WRIGHT. I can make a couple of comments on it, Mr. Chairman. One of the recommendations of our own internal study for post-earthquake investigations is to give a lot more attention to documentation of the damages, not simply looking at the most interesting collapses and the most interesting successful performance but really identifying just how much damage occurred and where.

And, similarly, the ongoing effort that FEMA is carrying out in the loss estimation study is going to give the knowledge for assessing the benefits, because based on this study we will be able to say what would happen if we did not improve our practices.

Mr. BAKER. Okay. Let me ask you a question, if you don't find that exciting.

Fifty percent of our losses is not dealing with structural damage. It's non-structural.

Is there anything that can be done about that?

Mr. MOORE. In fact, a good portion of the mitigation funds that are going to the State of California will be used for non-structural activity within the school systems. The formula that was changed by the Congress for post-disaster mitigation some two years ago following the midwest floods significantly increased post-disaster resources.

And, that's going to mean somewhere on the order—depending upon what the final bill comes in at in California—about $700 million. And, California has chosen to use it for non-structural retrofitting of the school facilities.

And, so that—and we are going to learn a lot, I think, from that process that will provide some important guidance for other states as well.

Mr. BAKER. They wouldn't be structural in the sense that it occurred because of the earthquake but it would be structural rehab, right?

Mr. MOORE. It's mainly the ceiling fixtures and the lighting and other kinds of materials that collapsed. The buildings themselves withstood, in many cases, much of the shaking.

It was the internal, the insides, the guts of the building basically that posed problems. And, a number of studies are being done on that particular issue as a result of that.

Mr. BAKER. We are replacing those now in the schools.

Mr. WRIGHT. Mr. Chairman, if I could comment?

Mr. BAKER. Yes.

Mr. WRIGHT. The non-structural damage is largely related to the nature of building codes. They are aimed to protect life and safety and not aimed at reducing property damage.

Actually, technically, the control of property damage is simpler than the control of structural collapses. But, it does require that the owner of the facility be willing to invest additional money, not required by the state or local building code, in order to reduce structural damage.

And, this is where the knowledge of the potentials for non-structural losses will be such a valuable incentive to owners to do relatively cost-effective things to reduce the non-structural damage.

Mr. BAKER. Great. Okay. For that, Peter, I would like to thank you once again.

Mr. GEREN. Thank you, Mr. Chairman. All of you were here, I think, and heard Dr. Abrams testimony.

Would each of you offer your observations on his recommendations of how we could spend an additional capital infusion? He had a minimum of $60 million and considerably more than that for upgrading some of the testing facilities or even building additional ones.

If we were able to secure an additional capital infusion, how would you recommend it be used?

Mr. BORDOGNA. Well, I think this sounds like an infrastructure issue for supporting and enabling the research to be done. NSF has been looking at this closely for the last three or four years.

It started with the idea that we don't have a big enough shake table. The one at California is 20 by 20 feet. And, the one in Japan is 18 by 18 meters. There is a large difference.

It's an enormous amount of money to build a big shake table and much more than the $60 million dollars, maybe three times that much. And, there has been a study of this.

And, as Dr. Abrams told you some of the results of that, as you look across the country at generic kinds of infrastructure, all kinds of disciplines, we have begun to take the view that we would like to build a partnership among some of the universities so this equipment infrastructure can be shared in many ways.

I will give you one example. In the small devices area, going from micro-structures to nano-structures, that are both electronic and mechanical small devices, there is a great need among many researchers for these devices to do other research. For example, putting small devices inside the body somewhere to do some investigations.

And, we had a center for many years being able to support that need as an infrastructure for the entire country. All research went right to that one university.

But, now the issue is so complicated, going from micro to nano, not one university can support all the equipment needed, nor can NSF or the government give many universities the specific things they need. So sharing is in order.

And, we have just inaugurated a national nano-fabrication users network with five universities that have different portions of the spectrum of infrastructure needed. And, they collaborate and provide a service to the entire country for that kind of research work to be done. So, it's an example.

Our thinking now is that we should look at what is extant and see if we can couple it in some way. That's one issue.

And, so $60 million is a rational number when you think that way compared to building one shake table.

Another issue here is—and I think it was mentioned by several people during the previous discussion—to put some intelligence into the infrastructure system so—simply said, it's computer simulations. But, give the system its extant, coupling it across universities and making it useful to lots of different researchers but making it more intelligent, applying computers and computer communications that can be accessed in different ways and do the simulation on a virtual sense.

In the end, this instrumentation is important for doing test bedding, too. So, NSF is thinking—would like to do some sharing of this.

We do believe that the recommendation on attacking the extant system first, the infrastructure in place, is the rational thing to do, because a lot can be done. As was pointed out by Dr. Abrams, it's not being totally utilized as it is.

And, that's because it's not updated or it's not connected or it's not accessible to people from different universities. So, that's the view we are taking right now.

And, we think it's a rational way to proceed.

Mr. GEREN. Would any of the other witnesses like to comment?

Mr. WRIGHT. In terms of Dr. Abrams' recommendations, my personal sense is the highest priority is the $40 million to $50 million per year to conduct research using these facilities. There is no use creating them if no one is going to use them.

And, if we look at the current amount of funding which goes into research in the existing facilities, it's probably on the order of $10 million to $15 million a year from all private sector and Federal sources put together. So, the most important problem is to be sure that the private sector and public sector funding to exploit the capabilities of these facilities will be there.

I would note, for instance, if the private sector and the Federal efforts worked together to be strengthened to the level of $40 million to $50 million a year, it would take several years to build up the human capabilities to spend this money well. And, indeed, in the early years, the funding could go for upgrading the facilities for the maximum part; and then, as the facilities are upgraded, the money can be put annually to proper use of those facilities.

Mr. GEREN. An interesting observation.

Mr. MOORE. I would add a couple of points with regard to the suggestion of collaborating with others and not building a whole set of these stand-alone type of operations. I think that that's particularly critical.

We have been directed by the Congress over the last four years to spend some money to develop a shake table at the University of Nevada, Reno, which is in the process of construction. And, one of the requirements we attached to that expenditure was that the University collaborate with the other shake table universities that exist in the country and with the private sector, with the Applied Technology Council, the Building Code organization, and others, to make sure that they were conducting research that was going to be directly applicable to the codes and to building standards so that we could put it into fairly early practice.

The other is that in the funding that we now have ongoing with the Steel Moment Frame Building study, one of the requirements of the second phase of that study is to work with the building industry, with the materials manufacturers and the contracting organizations, and others, to have them share a part of the cost of the study and the implementation particularly of that study and the findings, once those are completed and worked into the codes.

Mr. GEREN. Thank you. Dr. Hamilton?

Mr. HAMILTON. I don't have anything.

Mr. GEREN. Thank you. I yield back my time, Mr. Chairman, in the interest of giving everyone an opportunity to ask questions.

Mr. BAKER. Thank you, Mr. Geren. How big is that shake table in Reno?

Mr. MOORE. It's actually a two-part shake table. I believe—I'm going to be maybe wrong on this, but I believe it's about a 24 by 24 table, two-parts. And, if someone here has a better figure on that, they can correct me.

But, it's designed primarily for bridges and lifeline type of testing. It can do structural, too, but it's more designed for the bridge test. And, they are doing a lot of work with DOT and others to provide that kind of information.

We are also building it in in an existing facility that the state funded. So, it's a joint project with the state as well.

Mr. BAKER. Thank you. Dr. Bartlett.

Mr. BARTLETT. Thank you very much. Dr. Wright, did I hear you say that there were 30 Federal agencies that had interests in this area and were funding various types of programs?

Mr. WRIGHT. Yes. We have 30 Federal agencies in the Interagency Committee on Seismic Safety and Construction.

It includes the agencies that are pure users, like the Postal Service and the General Services Administration, people who have very important building inventories. And, it's extremely important that they be consulted in determining what they are going to be required to do for their facilities.

And, it includes research agencies that are not presently part of NEHRP, such as the Corps of Engineers.

Mr. BARTLETT. In your view, is there adequate coordination amongst these agencies so that we don't have duplications or gaps?

And, if there isn't, is there something that we need to do so that all of these various interests are appropriately coordinated in the future so that we don't have duplications and don't have gaps?

Mr. WRIGHT. I think we need a sustained effort for coordination. It's not something that is done once and takes care of itself forever thereafter.

There has been very good coordination through the Interagency Committee on Seismic Safety and Construction on getting the agencies to work consistently in the practices that they are using. So, if the same architectural engineering firm on one side of the street is doing a post office and on the other side of the street is doing a hospital, they will be using consistent seismic practices.

And, the efforts within NEHRP have done a good deal to coordinate the research activities among the agencies.

Mr. BARTLETT. Is there a lead agency or is the lead assumed by this Committee?

Mr. WRIGHT. The Interagency Committee on Seismic Safety and Construction has a secretariat and a chair which come from NIST. I happen to have been the chair for a few years.

But, we do work by consensus procedures. We don't tell the General Services Administration, "You have to do it this way or that way."

Everyone votes. And, the votes are considered. And, we are sure that we agree rationally with every concern that every agency has when a recommendation is made.

Mr. BARTLETT. Well, I suspect that you are well ahead of many other areas in government where we have a number of agencies working in a similar area and they are not coordinating. And, it's to the credit of all the agencies in this area that they are.

Dr. Bordogna, do you think that basic—is basic research leading in any meaningful way to better prediction?

Mr. BORDOGNA. Well, yes. My colleague, Bob, here listed knowledge about earthquakes that happened way in the past that wasn't available until now. And, that comes from investing in fundamental discovery modes by individual investigators primarily.

So, at NSF, the budget is one-third for investigations into geosciences on prediction and other issues related to that; and, two-thirds is for the engineering process to investigate new structures that would mitigate against what is being discovered. So, there is a tie there.

So, the answer is yes. And, I think there is much more to be discovered. It was pointed out that in Los Angeles it was a different kind of fault that hadn't been thought about before.

And, so we have to understand that. There is a lot of research.

It happened. We know why it happened—we know that it happened but we don't quite know why it happened and how to prevent against it. It is a different kind of force that happened there.

And, it has a lot to do with the testing again. We have been testing things for different kinds of forces. This is a new kind of force.

So, yes, basic research is critical.

Mr. BARTLETT. My next question is for Dr. Hamilton. And, then you can comment.

If we can have better prediction, then, very clearly, if we didn't do anything to improve buildings or lifelines or anything else, just knowing when it was going to happen, we could really limit the damage that was done. And, I was wondering what kind of progress we were making in that area.

Mr. HAMILTON. Okay. Let me start with the first question and then lead to the second one.

Mr. BARTLETT. Okay.

Mr. HAMILTON. I think, in responding to the first question, Dr. Bordogna was really referring to prediction of effects and prediction of where and perhaps how often earthquakes will occur. And, I agree with his point on that, that, yes, we are making progress.

As to predicting when earthquakes occur, I think we would have to say we are making no progress. There is no method currently known that allows us to predict the time of occurrence of an earthquake.

Mr. BARTLETT. Is there any hope that we will be able to do better at that in the future?

Mr. HAMILTON. Well, we have worked on it very hard. Back in the 70s, there were very encouraging reports that came from the Soviet Union at that time and China.

And, we undertook cooperative programs with those countries and attempted to learn everything we could about what they are doing. And, we followed up with our own experiments.

We currently have one, what you might call, earthquake prediction experiment underway. This is in the Parkfield area of central California, about halfway between San Francisco and L.A.

It's not actually a prediction experiment. It's an experiment to determine whether earthquakes have precursors or not.

And, in that area, we've had a sequence of five magnitude 6 earthquakes with an average return time of 22 years. And, the last one was in 1966.

So, we staked out the area. And, we have been waiting since 1988 for the earthquake to occur.

Our goal is to try to get instruments close into the source to trap an earthquake in the sense of seeing whether there are premonitory phenomena. That earthquake has not yet occurred.

Almost always when there is a large earthquake, in hindsight there are reports of something that happened beforehand. The water turned muddy. The chickens flew up into the trees.

Or, there was a small flurry of earthquakes that somebody said, "Ah, ha, those were fore-shocks." Of course, you don't know they are fore-shocks until after the event.

So, we pursued it. We continue to have this one experiment, which we feel is well founded and should be continued.

But, the answer to your question is no, there is no method to predict the time of occurrence. And, so prediction is no substitute for sound engineering and sound land use.

Mr. BARTLETT. Just one additional question on this same subject, then, for Mr. Moore. If that's true, then, how can you develop a nationally-applicable standardized method for estimating potential earthquake losses on a regional basis if you have no idea when they are going to occur?

Mr. MOORE. No, but it's looking at the structures that are in place, looking at the built environment and then calculating the impact of various magnitudes of——

Mr. BARTLETT. Oh, so this is losses if it occurs, if and when?

Mr. MOORE. That's right.

Mr. BARTLETT. Okay.

Mr. MOORE. And then calculate what you need to do to protect those facilities, particularly critical facilities like hospitals and others.

Mr. BARTLETT. Okay. Thank you very much.

Mr. BAKER. Who do you select to man that station down there waiting?

Since 1988, who has been standing there waiting for this——

[Laughter.]

Mr. HAMILTON. Well, the fact is the school teacher, the teacher in Parkfield.

[Laughter.]

Mr. HAMILTON. We have hired the school teacher to go out and run the laser every night. And, of course, a lot of these——

Mr. BAKER. So, he is doing instrument readings hoping that it doesn't occur?

Mr. HAMILTON. Well, I think they look forward to it.

[Laughter.]

Mr. BAKER. I won't comment. I won't comment on the NEA. Okay, Dr. Ehlers.

Mr. EHLERS. Thank you, Mr. Chairman. I find earthquake prediction very easy. I predict we will have a major earthquake somewhere on the earth next year.

[Laughter.]

Mr. EHLERS. You know, it's narrowing the window that is the problem, both the location and time window that becomes a problem.

Also, just another comment. I hope you do find some precursors, but I am sure you have no problem finding post-cursers after every earthquake, spelled e-r-s.

I don't have any questions, Mr. Chairman. But, I do have a comment based on the testimony this afternoon and based on some other things happening in the Congress this year.

I was astounded when I arrived in Congress two years ago to find that there are some people here who think the USGS should go out of business, should be terminated. And, I, for years, have had a lot of respect for the USGS as an agency. And, I think they do great work.

Similarly, this year, there have been proposals that I think would have done severe damage to the National Institute of Standards and Technology. Fortunately, the Science Committee has studied that very carefully.

And, I think we've come up with a good solution if the Department of Commerce is restructured, a solution which might, in fact, benefit the current NIST and even make it back into the National Bureau of Standards, which I suspect some of the old timers would appreciate.

I think it's very important for us on the Science Committee to not only realize the good work these agencies do—and we heard testimony earlier that the cost of what we are spending, even if we were to provide the money that was mentioned in the first panel, which is more than we are spending now, the cost would be approximately one-thousandth of the cost of a major earthquake in the United States. Now, there aren't very many things that you can spend .1 percent on and get that kind of return.

And, yet, we continue to have—some of our colleagues continue to hold these efforts in low regard. I think it's incumbent upon the Science Committee to start spreading the word to the Congress of the good work these agencies do.

Science seems to be a favorite target in budget cutting. And, we simply have to make our colleagues, as well as the rest of the world, aware of the return on the dollar that we are getting in some of the agencies that are doing research in this area and other areas.

And, so I hope the Science Committee members will join me in that. Thank you.

Mr. BAKER. Sherwood Boehlert, which is a low to medium density risk area as far as earthquakes, has joined us. Sheri.

Mr. BOEHLERT. Thank you, Mr. Chairman. First and foremost, I wish to associate myself with the remarks just made by Dr. Ehlers. I couldn't agree more with what he just said.

And, we are part of the vanguard trying to convince some of our colleagues of the wisdom of his words. Out of the mouths of babes, you know.

Let me ask, Dr. Hamilton, I understand that USGS is developing maps and earthquake scenario predictions in and around the region of the Northridge earthquake. Would it be realistic to task USGS with producing maps like this for all earthquake-prone areas in the U.S.?

Mr. HAMILTON. It certainly could be done. The development of earthquake scenarios is fairly well established.

And, it's not just the U.S. Geological Survey that does it. The state agencies do it.

FEMA has funded the development of scenarios. And, a number of organizations participate in this.

And, it turns out to be a very good preparedness and planning technique. It helps to put in tangible terms what might happen and it gets the authorities to start thinking about what they could do to reduce the losses.

Mr. BOEHLERT. Well, you know, what we need in addition to authorities thinking about what we can do to prevent the damage, in the first place, but reduce it if the inevitable occurs, I think we've got a job to do of public education. You know, I go in beautiful upstate New York, my home district, and they think earthquakes are the exclusive domain of California, for example.

And, I think there are a lot of areas—I know there are a lot of areas—of the country that are earthquake-prone. And, perhaps if our citizenry were better informed and on the alert, they might be doing a better job of writing to their representatives in this distinguished institution to encourage us to do some of the things that we should be doing, which were mentioned by Dr. Ehlers just a moment ago.

Mr. HAMILTON. I think you've put your finger on the central problem that we face. It's almost worse than you can imagine, I think.

I attended the second workshop that Moore convened in developing the National Mitigation Strategy. This was in Harrisburg, Pennsylvania.

And, a member of the audience stood up and said, "Over half of the communities in Pennsylvania don't have building codes. And, we like it that way."

Mr. BOEHLERT. They took pride in that?

Mr. HAMILTON. And, so to progress from that attitude toward one where the public demands safer structures represents quite a challenge. And, I think that, in the development of the National Mitigation Strategy, FEMA has addressed that issue and has structured the program to try to develop that change in public attitude.

Mr. BOEHLERT. You know, on a different subject, I was just down to St. Thomas which suffered the devastation of Marilyn. And, let me once again say, as I've said many times before, I could not be more impressed than I am with the outstanding work that FEMA is doing.

But, on a hill—and St. Thomas has many hills—there were all these structures that the roofs or top stories had been just completely torn off of. But, right in the middle of it all, like an oasis in the middle of the desert, were two structures that looked like they had been constructed the day after Marilyn arrived instead of two or three years before to very stringent codes.

And, mitigation is so critically important. And, people don't want to pay for it. But, boy, I would suggest, in retrospect, a lot of people look and say, "Gee, maybe we should have."

I don't have anymore questions, Mr. Chairman. But, I do want to seize this opportunity to say I was privileged last week to attend a ceremony in which one of our colleagues, Dr. Ehlers, was inducted as a Fellow in the American Physical Society.

And, I want to say how comforting it is for me to sit here on this Committee on Science next to someone so distinguished in his field of science. And, it proves that Congress does do things right on occasion.

Isn't it refreshing to see this very eminent scientist on the Science Committee?

Now, with me, I came to Congress back in 1982. And, they looked at my resume and said, "The last science course Boehlert took was high school chemistry, and he got a C. Let's put him on the Science Committee."

[Laughter.]

Mr. BOEHLERT. At least, we've improved the way we operate around here. Dr. Ehlers, congratulations to you.

Mr. EHLERS. Will the gentleman yield?

Mr. BOEHLERT. I will be glad to yield.

Mr. EHLERS. First of all, thank you very much. But, secondly, I wish to point out that we are blessed with three eminent scientists on this Committee—one sitting to my immediate right has a very distinguished scientific career, and also Dr. Olver, who is unfortunately not here at the moment.

But, I think we try to be a real asset to the Committee. And, I appreciate your comments.

Thank you.

Mr. BAKER. Well, with that brief pat on the back, we will move right along. And, I want to thank the panel for their hard work. I appreciate it.

We will start with Panel 3 right away. Dr. Paul Somerville is a seismologist at the Woodward-Clyde Federal Services in Pasadena, California, where he has a bird's-eye view of most of the earthquakes.

Dr. Thomas Anderson, Fluor Daniel Corporation, representing the NEHRP Coalition, from Arlington, Virginia; Dr. Thomas Jordan, Chair of the Department of Earth Science, Massachusetts Institute of Technology from Cambridge, Massachusetts; and, Dr. Anne Kiremidjian, Department of Civil Engineering at Stanford University.

Thank you. Dr. Kiremidjian, why don't we start with you? You will be the lead off.

STATEMENT OF DR. ANNE S. KIREMIDJIAN, PROFESSOR OF CIVIL ENGINEERING AND DIRECTOR OF THE JOHN A. BLUME EARTHQUAKE ENGINEERING CENTER, STANFORD UNIVERSITY, STANFORD, CALIFORNIA

Ms. KIREMIDJIAN. Mr. Chairman, members of the Committee, thank you very much for giving me this opportunity to speak to you. This is my first time addressing any committee in the House or the Congress, so if I appear a little bit nervous you will excuse me.

Mr. BAKER. Please, don't be nervous. In spite of all these learned minds around you, this is a very simple committee. And, we would just love to hear what you have to say.

Ms. KIREMIDJIAN. Thank you. Let me, first of all, tell you that over the past 23 years I have been involved in research education and implementation of earthquake engineering.

And, most of my support has come from the National Science Foundation where it has been primarily in research and education; and, to some degree, from the U.S. Geological Survey, NIST. In relationship to the implementation projects that I have been involved in, that support has come primarily from FEMA.

Through my experience, I have seen both research being conducted and I've seen that research being translated into implementation and policy programs.

I would like to start my comments by saying that, in my opinion, NEHRP has made some very significant and very important advances in the effort toward this earthquake hazard. I think some of the comments that were made earlier by the individual representatives from the agencies summarized very nicely some of the major contributions that have been made under the NEHRP program.

I concur with each and everyone of them in terms of those contributions.

In my opinion, these advances have been both in research and implementation. And, I find it rather surprising, over the years, to hear the criticism of how research has now been translated into implementation.

Coming from the research community, the very first comment I would make is that if, indeed, implementation is lagging by several years from research, that is only natural. If research was not several years ahead of implementation, we shouldn't call it research. That's the very first comment I would like to make.

So, it is natural that it will take several years until that research gets translated into implementation.

In response to the criticism that the NEHRP Coalition has drafted—let me back that up again. Several years ago, during the 1993 hearings, there were several criticisms brought out by the review panel. And, this afternoon, we also heard comments from Mr. Komor regarding the lack of coordination between the various agencies and lack of specific goals that NEHRP can follow.

In response to those criticisms, the NEHRP Coalition has drafted a strategic plan. And, I believe Mr. Anderson will summarize that plan in a few minutes.

I would like to—I've had the opportunity to look at the plan. And, I would like to say that I'm very impressed with the thorough work that has been done by the Coalition.

And, I concur with the way the plan has been developed. And, they need to be congratulated for the excellent work that they have done.

There are several issues in that plan that do concern me. And, at this time, I would like to bring those issues.

The first issue is implementation versus research. Although the strategic plan recognizes the importance of research and many elements of the plan address research components, the overall emphasis is on implementation.

I can understand that this is a reaction to the criticism of NEHRP. I agree that it is through extensive implementation that we will be more effective in enforcing the earthquake hazard.

However, I find this approach to be somewhat shortsighted; for, if we do not continue our effort in research, both basic and problem-focused, we will find ourselves in only a few years with little to implement and not having resolved the problem of earthquake hazards.

The second concern is with the centralized management plan and, in particular, with the establishment of a program office to be headed by a member from FEMA. I believe that question was raised a little earlier today, as well.

While there are many capable individuals at FEMA who, in principle, would be qualified to head this effort, I believe very strongly the director of that office should not necessarily come from any one particular agency. And, it should be an individual who understands the overall goals of NEHRP and has an understanding and appreciation for the missions of each and everyone of the agencies.

This individual will have the difficult task to bring the agencies together toward the NEHRP goals, toward a well-coordinated effort. Perhaps this person should be from outside of all the three agencies.

Another issue that was brought up was related to the testing procedures, of structures, especially in view of the performance of steel structures in the Northridge earthquake. In general, laboratory testing is critical component of the earthquake engineering research process.

I would like to take this opportunity to raise an awareness in this Committee that over the past decade we have allowed our laboratories to deteriorate, with much of its equipment now outdated and obsolete. All you have to do is come and look at our laboratory, which has not been renovated since 1975. Equipment has not been renewed simply because of lack of funds.

Support provided primarily by NSF for actual testing and experimentation has decreased over the years, mostly due to continued decreasing funding in NEHRP.

There is a gap between analytical modeling and real life performance of structures subjected to earthquakes. Earthquake events provide a natural laboratory for evaluation of performance of various types of structures and verification of our design methods.

Since the 1971 San Fernando earthquake, we have been instrumenting buildings in order to evaluate their performance.

Modern buildings, however, have not been subjected to a truly great earthquake, such as the 1906 San Francisco earthquake, thus making it difficult to truly predict the performance of structures.

We can expect that we can continue to improve our design methodologies. Laboratory experimentation will attempt—thus attempt to bridge the gap between analytical models and the real life performance of structures, but it can do so partially.

The main reasons for deficiencies in real structures are introduced because of the scaling of materials and geometric properties, which can be evaluated only through full-scale testing. Such full-scale testing, however, is economically prohibitive, since a single test may exceed the entire NEHRP budget.

In order to reduce the potential for major catastrophic failures, our ongoing efforts need to continue on integrating fundamental analytical developments, small and large scale testing, data and information gathering after each significant earthquake and practical considerations.

In conclusion, the National Hazards Reduction Program has, or is about to, embark on an aggressive implementation program. At least, that's the way it appears to me.

Such an approach necessarily requires the integration of research from earth sciences, engineering, economics, sociology and public policy and the translation of this research in an appropriate mitigation program. The draft strategic plan for the National Earthquake Loss Reduction has laid out the road map for achieving the goals of NEHRP over the next decade.

It is important, however, as we enter this implementation phase, that our efforts continue to improve our knowledge about the fundamentals of earthquake phenomenon, the performance of different structures and the socioeconomic consequences to be—the socioeconomic consequences to be enforced through sustained funding. We also should not forget that it is through innovation and knowledge that we can continue to effectively mitigate natural disasters.

Furthermore, it is through improved building codes, appropriate education of the public and the professions and prudent enforcement policies that we can decrease the potential losses of life and can alleviate major economic disasters. Finally, our ability as a nation to respond to the public in the event of a catastrophic earthquake hinges on our ability to implement new technological tools as well as the development of realistic emergency response plans that balance our resources with the needs.

Thank you.

[The prepared statement of Dr. Kiremidjian follows:]

WRITTEN TESTIMONY OF ANNE S. KIREMIDJIAN

Professor of Civil Engineering and Director of
The John A. Blume Earthquake Engineering Center
Stanford University

before the

SUBCOMMITTEE ON BASIC RESEARCH
COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES

October 24, 1995
2318 Rayburn House Office Building

HEARINGS ON
THE NATIONAL EARTHQUAKE HAZARD REDUCTION PROGRAM

Chairman Walker and Committee Members, thank you for the opportunity to speak as a participant of the research supported by the National Earthquake Hazard Reduction Program (NEHRP). I have addressed several of the issues raised in your letter to me.

1. NEHRP Strategic Plan, Long Term Goals and Management Structure

After a careful review of the draft Strategic Plan developed by the Coalition of Professional and Scientific Associations in Support of NEHRP, I found the plan to be comprehensive, well thought out and very effective in addressing criticism raised previously in relationship to the program. I would like to bring several concerns to your attention.

My first concern is related to the proposed management structure and, more specifically, to the establishment of the Program Office. While I agree that there is a need for a coordinated effort on the part of the different NEHRP agencies in order to achieve the goals and the objectives of the program, each agency should be given latitude to develop programs that are in support of their primary mission. A Program Office under the auspices of FEMA may focus primarily on implementation of existing technologies. For example, NSF and USGS have responsibility to support basic research as well as problem focused or need based research. It is basic research that enables us to extend the horizons of our knowledge ultimately leading us to improved mitigation methods. Thus, it is essential that these programs' ability to develop a well balanced research agenda be preserved.

My second concern is with the recommendation that the funding for the Program Office be allocated from the existing NEHRP funds. If the budget for this office becomes a significant proportion of the overall NEHRP funding (e.g., more than 3-5% of the overall budget), then it is highly recommended that that new funds be sought for that office. Given the fact that funding has decreased over the past decade, allocation of funds from the existing NEHRP agencies would further impair their ability to fulfill their mission.

2. Short-Term, Applied Research vs. Basic Research in Earth Science

Since its inception, the National Earthquake Hazard Reduction Program has conducted both basic and applied (or problem-focused) research. Continued support of basic research is imperative. It is primarily through basic research that we will continue to improve our understanding and knowledge about the earthquake phenomenon and its effect on the built environment. It is through extensive instrumentation and measurements that we are able to monitor crustal movements, map existing faults and identify areas with the greatest potential for seismic activity. While we are far from predicting earthquakes, measurements and monitoring of seismic activity have enabled us to greatly improve our understanding of where earthquakes occur, how geologic characteristics affect activity along faults, what are the major factors influencing ground motion propagation, and what secondary hazards (such as liquefaction, and landslides) are likely to occur in various regions.

Much of the information developed in recent years has been utilized in the development of national seismic hazard maps. In addition, USGS has published reports identifying high seismic hazard areas with likelihoods of occurrence of events and their sizes. The hazard maps form the basis for seismic building code regulations. USGS is currently in the process of developing a new national map which attempts to implement some of the latest earth science findings and techniques. A major improvement in the process of developing these maps has been the coordination of the mapping efforts with several state agencies, such as the California State Division of Mines and Geology, and the various user communities, such as the scientists/researchers and the engineers/designers.

In addition to the national seismic hazard maps, it is of great importance to develop microzonation maps identifying local seismic hazards. Such maps, currently exist for very few regions in the country and, for locations where they do exist, they are often greatly outdated not reflecting current knowledge. Such information is imperative for the implementation of regional seismic risk and loss estimation methodologies which are the basis for the long term earthquake disaster mitigation programs and emergency response planning. Effective mitigation measures can be developed and implemented only if the hazards are adequately identified and quantified.

The USGS program, however, goes well beyond the mapping efforts described above. The agency is the primary provider of information critical to any earthquake hazard and risk studies. It serves as a repository of critical earthquake data and geological, seismological and geophysical information utilized by engineers, policy makers and various business entities. These functions are essential to the continued success of the NEHRP program.

Thus, the program should be balanced between (a) basic and applied research, (b) problem focused studies to develop, evaluate and implement earth science results in design/retrofit guidelines and earthquake mitigation policies, and (c) education and training. Considerably improved support can be provided by USGS programs through continuous communication and interaction with the engineering and public policy communities. In addition to exploring innovative means to the understanding of seismic effects, the earth science community should identify unresolved issues that are of critical importance to the engineers/designers and public policy makers filling in gaps in our knowledge.

3. Lessons From the January 17 Northridge (1994) and Kobe (1995) Earthquakes

The Northridge and Kobe earthquakes are the first two events since the authorization of NEHRP that struck in the hearts of major metropolitan areas. They are a sobering reminders of the great devastation that can take place even if the earthquake is of moderate strength. They have revealed once more that our cities are populated with large stock of vulnerable buildings and lifeline systems that can cause staggering economic losses, large number of casualties and major business interruption. The long-term economic consequences from these events will not be understood for sometime. While many of the lessons were not new, the two earthquakes brought a renewed realization of the degree of chaos that such events can cause.

The following are important lessons that can be drawn from these two events:

- The first and foremost lesson to be learned from the Kobe earthquake is that the earthquake hazard will not go away. Just because there has not been an earthquake within the last few decades, it does not mean that the region has become quiescent. There are many regions within the United States where the earthquake threat is real, yet little is done to mitigate its effect mostly due to public and political complacency. We need to continue our effort to identify all areas with moderate and high seismic hazard potential and proceed to implement appropriate mitigation policies. The NEHRP program has been successful in identifying global seismic hazards in the United States, but often, because of the vast areas to be covered we have concentrated on major known fault zones. The Northridge earthquake occurred on a previously unidentified fault. Thus, it is imperative that we continue our effort to map regions and identify fault features, their activity and their likelihood to generate significant earthquakes. This is a difficult and time consuming task that will take decades to complete to a satisfactory level. New technological tools and instruments are becoming increasingly more effective in speeding this process. Nevertheless, this costly process requires sustained effort over a long period of time and the NEHRP program needs to recognize that achievements in this area will be incremental.

- Ground motions in close proximity to the fault rupture zone are considerably greater than previously observed. Studies are still continuing to fully understand the near-field large velocity pulses generated by these earthquakes and to evaluate their effect on structures. In addition, strong motion recordings from the Northridge earthquake point to important difference in the ground motion depending on the fault structure and movement (motions over the hanging vs. foot wall of a trust fault). Considerable additional studies will need to be conducted to fully understand the mechanisms and implications of the ground motions from these events. The NEHRP program has been vital for the development of better, more efficient and more accurate instruments and the installation of greater seismic networks. These programs have been crucial for our improved understanding of earthquake ground motion. It is with this type of sustained research effort that our ability to develop appropriate mitigation measures, such as seismic building code requirements and land use policies, will vastly enhanced.
- The Kobe earthquake demonstrated also that, even when buildings are designed properly to withstand seismic forces, their functionality can be severely impaired due to geotechnical or lifeline failures. Very few new geotechnical lessons were learned from that event. However, that earthquake and the Loma Prieta earthquake of 1989 point to the lack of policies that would enforce the implementation of appropriate mitigation measures. Such policies need to evaluate the implications to existing hazardous structures (buildings and lifelines) and geotechnical conditions, as well as to new structures and land developments. A critical component of these policies should be an educational process for the public and the individual owner. As these policies are being developed to implement existing knowledge, efforts should continue on gathering of information on local soil properties, the development of better and more robust analytical tools to quantify soil behavior, and expand instrumentation of various types of soils and topographies in order to improve our understanding of the in-situ behavior of these soils. Provisions also need to be made to implement new knowledge as it is developed.
- Failures of lifelines in the Northridge and Kobe earthquake have pointed to the lack of guidelines for the expected performance of utilities and other lifeline systems. Most utilities in the United States are self-regulated and performance standards vary between utilities. Thus, performance guidelines need to be established that are in compliance with functional requirements of individual lifelines, other dependent lifelines and the structures that they service.
- The performance of buildings in the Northridge and Kobe earthquakes point again to the fact that our greatest peril is with existing older structures. Even though much of the damage to structures in these earthquakes could have been predicted, the extensive damage to steel structures primarily with welded connections was a surprising new finding. Over the years, the NEHRP agencies have supported important efforts in the establishment of structural rehabilitation and seismic upgrading procedures for hazardous buildings other than steel structures. Problem focused programs supported by NSF have provided the fundamentals tools for developing seismic rehabilitation methods. These have been implemented in design guidelines by FEMA. Current programs undertaken by FEMA to evaluate the performance of steel structures

and develop new design and rehabilitation guidelines for existing and new steel structures is a clear example of the critical functions that NEHRP plays in mitigating earthquake risks. In general, efforts need to continue to develop new, more cost effective methods for seismic upgrading and to provide guidelines or policies for implementing these measures.

- The Kobe earthquake tested emergency response capabilities to the fullest. Similar and larger earthquakes can be expected over the next few decades in major urban areas in the United States. The Northridge earthquake tested to a lesser degree the capabilities of Federal, State and local emergency response systems. It is imperative that the lessons from these earthquakes be used to create prudent emergency response plans. New technologies (e.g, geographic information systems, database management systems, and satellite imagery) should be utilized to aid with important decisions immediately following an earthquake. After the Northridge event, loss estimates were obtained employing some of these technological tools. However, much remains to be developed and implemented to enable emergency response personnel to act in an informed and efficient way. The NEHRP goal should be to have such technologies in operation when the next major earthquake strikes.
- The Northridge and Kobe earthquakes have also pointed to many societal and economic issues that are the result of not only earthquakes but any natural catastrophe. Many of these issues are regional and as such they need to be addressed with these differences in mind. Over the past 18 years, NSF and FEMA have supported programs that have brought better understanding of some of the critical issues such as effects on multicultural societies, public education and emergency response. The long-term implications of earthquake disasters on the affected societies and institutions is a problem that still needs to be addressed in future years.

4. Adequacy of Laboratory Research for Welded Steel Structures

In general, laboratory testing can be considered adequate for evaluating the performance of steel welded joints. However, the relatively poor performance of steel structures during the Northridge and Kobe earthquakes points to a more fundamental problem. There are numerous issues that have been raised in relationship to the performance of steel structures one of which is the cracking of the welded joints. Studies are still underway to understand the underlying mechanisms of crack initiation and propagation in such joints. An unresolved problem is the identification of whether cracks were initiated by the earthquake and propagated by the large vibrations, or whether cracks were already in existence and were aggravated by the earthquake. What size cracks are detrimental to a joint and at what point should a structure be considered hazardous? What demands are placed on structural components and the systems as a hole? Are our current analytical and design tools adequate to evaluate the performance of these structures?

Over the next few years, the engineering and scientific community through cooperation between practitioners and academicians will be addressing all these issues. Resolving these questions will require:

- extensive laboratory testing of components;
- development of new analytical tools (e.g., three dimensional nonlinear dynamic analysis techniques) that will enable a more accurate and reliable assessment of the performance of structural components and systems; emphasis should be placed on systems performance.

- exploration of new designs and materials that may alleviate the problem associated with welding of steel joints;
- development of nondestructive testing and health monitoring methods for the evaluation of the state of existing structures before an earthquake and immediately after an earthquake;
- development of seismic upgrading procedures for steel structures found to be deficient in their seismic resistance;
- development of policies for implementation of seismic rehabilitation and upgrading of deficient structures;
- development of periodic structural maintenance of structures that would enable identification and correction of problems that may have been caused under normal conditions but can become detrimental in the event of an earthquake.

In general, laboratory testing is a critical component of the earthquake engineering research process. I would like to take this opportunity to raise an awareness in this committee that over the past decade we have allowed our laboratories to deteriorate with much of its equipment outdated or absolete. Support, provided primarily by NSF, for actual testing and experimentation has decreased over the years mostly due to deteriorating funding in the NEHRP. There is a gap between analytical modeling and real life performance of structures subjected to earthquakes. Laboratory experimentation attempts to bridge that gap, but it can do so only partially. The main reason for this deficiency is that real structures are of vast dimensions making it difficult to test in the laboratory. Errors and uncertainties are introduced through scaling of material and geometric properties which can be evaluated only through full scale testing. Such testing, however, is economically prohibitive since a single test may exceed the entire NEHRP budget. Earthquake events provide a natural laboratory for evaluation of the performance of various types of structures and verification of our design methods. Since the 1971 San Fernando earthquake we have been instrumenting buildings in order to evaluate their performance. Modern buildings, however have not been subjected to a truly great earthquake, such as the 1906 San Francisco event, making it difficult to truly predict the performance of structures. Thus, we can expect that as we continue to improve our design methodologies, future surprises are likely. In order to reduce the potential for major catastrophic failures, our ongoing efforts need to continue integrating fundamental analytical developments, small and large scale testing and practical considerations.

5. Conclusion

The National Hazard Reduction Program has embarked on a more aggressive implementation program. Such an approach necessarily requires the integration of research from earth sciences, engineering, economics, sociology and public policy, and the translation of this research in an appropriate mitigation program. The draft Strategic Plan for National Earthquake Loss Reduction has laid out the road map for achieving the goals of NEHRP over the next decade. It is important, however, as we enter this implementation phase, that our efforts to continuously improve our knowledge about the fundamental earthquake phenomenon, the performance of different structures and the socio-economic consequence be enforced through sustained funding. It is through innovation and knowledge that we can continue to mitigate the effects of natural disasters. Furthermore, it is through improved building codes, appropriate education of the public and professions, and prudent enforcement policies that we can decrease potential loss of lives and can alleviate major economic disasters. Finally, our ability as a nation to respond to the public in the event of a catastrophic earthquake hinges on our ability to implement new technological tools as well as on the development of realistic emergency response plans that balance our resources with the needs.

RESUME

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B.S. in C.E., Columbia University, New York, June 1972
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M.S. in Struct. Engr., Stanford University, Stanford, CA, June 1973
Ph.D. in Struct. Engr., Stanford University, Stanford, CA, January 1977

Professional Experience:

1994-present	Chairman of the Board, K2 Technologies, Inc.
1991-present	Professor of Civil Engineering, Stanford University, Stanford, CA
1995-present	Director of the John A. Blume Earthquake Engineering Center, Stanford University, Stanford, CA
1987-1994	Co-Director of the John A. Blume Earthquake Engineering Center, Stanford University, Stanford, CA
1985-1991	Associate Professor, Stanford University, Stanford, CA
1978-1985	Assistant Professor, Stanford University, Stanford, CA
1976-1978	Postdoctoral Research Affiliate, Stanford University, Stanford, CA
1976-1977	Visiting Lecturer, Dept. of Civil Engrg., Stanford University, Stanford, CA

Professional Societies:

EERI, ASCE, SEAONC, SSA, IASSAR

Awards:

School of Engineering Distinguished Advisor Award, Stanford University, June 1989
National Science Foundation Faculty Award for Women, 1991-1995
Society of Women Engineers Distinguished Educator Award, 1992

Honors:

Member of Tau Beta Pi, Sigma Xi; Elected to Who is Who in California, 1982, Who is Who in the West, 1985

Active in the Following Professional Committees:

Probabilistic Methods Committee of the Engineering Mechanics Division of ASCE
Seismic Risk Committee of EERI
Committee on Building Instrumentation, CSMIP, California Seismic Safety Commission
Committee on Stochastic Methods in Structural Engineering, IASSAR
Vice -Chairman, Executive Committee of TCLEE, ASCE
Advisory Committee to the Biological and Critical Systems Division of NSF
Fellow and Advisory Board Member of the Stanford/USGS Institute for Research in Earthquake Engineering and Seismology
Member of the Board, CUREE, Treasurer
Member of the , New York State Committee on Low Level Nuclear Waste Management, NAS
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On the Editorial Board of:

The International Journal of Soil Mechanics and Earthquake Engineering
International Journal of Structural Safety
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The International Journal of Earthquake Engineering and Structural Dynamics
Bulletin of the Seismological Society of America
Journal of Structural Engineering, ASCE
Journal of Engineering Mechanics, ASCE
Journal of Probabilistic Engineering Mechanics
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Research and Teaching Interest:

Dr. Kiremidjian's general research interests are within the area of probabilistic methods in civil engineering. She specializes in developing models for earthquake occurrences, ground motion characterization, structural damage evaluation and reliability analysis of structures. Dr. Kiremidjian currently teaches courses in the Department of Civil Engineering at Stanford University on probabilistic methods in engineering, structural analysis, earthquake engineering, structural reliability, and strength of materials.

Academic Advising:

Professor Kiremidjian is currently the primary dissertation advisor to five doctoral students and two masters degree students. During her academic career she has been the primary advisor or has served on the dissertation committee to more than twenty doctoral students.

Research Projects:

Professor Kiremidjian has been the primary investigator to fifteen research projects ranging in amounts from $100,00 to $350,000 awarded from variety of funding agencies including the National Science Foundation, the National Center for Research in Earthquake Engineering, the Electric Power Research Institute, United States Geological Survey, California Department of Transportation, and California Universities for Research in Earthquake Engineering.

Consulting:

Dr. Anne Kiremidjian has served as a consultant to several structural engineering companies and other corporations. These include Chevron Corporation, URS/John A. Blume & Associates, Black & Veatch, EQE International, Forell Elsesser Engineers, Rutherford and Chekene, and CH2MHill. In addition, she has been a consultant to various institutes (e.g., Electric Power Research Institute and Applied Technology Council), and government agencies such as the Nuclear Regulatory Commission and the Federal Emergency Management Agency. As part of her consulting work, she has been involved in the development of (a) seismic reliability methods for large spherical ammonia tanks and tall columns found at oil refineries and other chemical plants; (b) multi-hazard risk analysis methods for major water supply systems; (c) regional seismic hazard mapping and site specific seismic hazard estimation models; (d) regional damage estimation models; and (f) implementation of geographic information systems, knowledge-based expert systems and database management systems in regional earthquake damage and loss estimation methods.

Publications

Dr. Kiremidjian has published over 100 journal papers, technical reports, and conference proceeding papers. She has been an invited and keynote speaker to major international conferences and makes frequent presentations at seminars and other professional meetings. A complete publication list can be provided upon request.

Mr. BAKER. Thank you. Dr. Anderson.

STATEMENT OF DR. THOMAS ANDERSON, FLUOR DANIEL CORPORATION, REPRESENTING THE NEHRP COALITION, ARLINGTON, VIRGINIA

Mr. ANDERSON. Thank you, Mr. Chairman, Congressman Baker. I appreciate the opportunity to address you on behalf of the Coalition of Professional and Scientific Associations in Support of NEHRP.

The Coalition is composed of 10 professional and scientific associations. The members of these groups represent the vast majority of the professional engineers, scientists, architects and public administrators conducting research on earthquakes and earthquake hazards mitigation.

The NEHRP Coalition strongly supports the reauthorization of NEHRP. And, we urge that the funding authorization levels for the program be increased substantially for the fiscal year 1997 and beyond.

Our justification for this request is tied to the urgent need for more rapid utilization of the lessons learned from the Northridge, California earthquake and the more recent Kobe, Japan disaster.

In recent years, numerous studies and reports have criticized NEHRP for the slow rate of adoption and enforcement of NEHRP research results. We need often to remind ourselves that NEHRP was not initially a mitigation implementation program. It was an earthquake science and technology research and development program.

And, the assumption was that the states, local jurisdictions, businesses and individuals would voluntarily and enthusiastically incorporate new mitigation technology and would push building code changes, would adopt new codes and would vigorously enforce them. This clearly has not happened.

The technology push is not working in this market. Incentives are required.

Our priorities for action for the future of a revitalized NEHRP are, in order. One, incentives; two, program management; and, three, technical issues.

We believe that incentives should be the cornerstone of a Federal natural hazards mitigation policy, a top priority. In the few minutes I have for my remarks, let me touch on two of our priority areas—incentives and technology issues.

NEHRP and its four program agencies do not have the authority to establish and enforce implementation regulations or to establish incentives, financial or otherwise. It, therefore, is clearly the responsibility of Congress either to establish Federal implementation regulations or financial incentives or both.

The NEHRP Coalition believes strongly that any combination should be heavily weighted on the side of financial incentive and have immediate impact and which are certainly the most effective and least objectionable.

Our third priority deals with technical issues. In my written testimony, we outline nine areas of research needs. And, we outline the research successes revealed by the Northridge earthquake.

Briefly, at least five major lessons emerge from that destructive event. Codes work. Retro-fitting works. Preparedness works. We are reminded that there is a huge inventory of collapse hazard buildings in the U.S. that poses a severe threat to the many earthquake-prone regions of this country.

And, Lesson 5 is that most of the $22 billion financial loss to businesses and industry from the Northridge earthquake was not in building damage and collapse. It was, rather, in non-structural losses.

We believe that the major risk from earthquakes is the enormous stock of potentially hazardous existing buildings and their contents. The financial losses in Northridge resulted from damage to building contents such as furnishings, inventory, vital records, equipment, telephones and the like.

Businesses that had not prepared were unable to function. Pay checks stopped. Market share was lost.

The impact on the people and the economy was profound. And, its effects linger on today.

Yet, these kinds of losses are preventable. But, they receive little attention under NEHRP.

It is a research area in which the payback ratio would be very high.

In conclusion, Mr. Chairman, we appreciate the opportunity to testify. We would highlight the fact that societal costs of earthquakes can—in fact, they must—be reduced by leveraging significantly smaller expenditures for loss prevention measures that can be put in place in advance of destructive earthquakes.

Thank you.

[The prepared statement of Dr. Anderson follows:]

**TESTIMONY OF DR. THOMAS L. ANDERSON
ON BEHALF OF THE
COALITION OF PROFESSIONAL AND SCIENTIFIC
ASSOCIATIONS IN SUPPORT OF NEHRP**

**BEFORE THE HOUSE SUBCOMMITTEE
ON BASIC RESEARCH
OCTOBER 24, 1995**

I. INTRODUCTION

This testimony is submitted in support of the reauthorization of the National Earthquake Hazard Reduction Program (NEHRP). The Coalition, which I am representing, is composed of ten professional and scientific associations: the Association of American State Geologists, the American Geophysical Union, the American Institute of Architects, the American Society of Civil Engineers, the American Society of Public Administration, the Applied Technology Council, the Association of Engineering Geologists, the Earthquake Engineering Research Institute, the Seismological Society of America, and the Structural Engineers Association of California. The members of these organizations represent the vast majority of the professional engineers, scientists, architects, and public administrators conducting research on earthquakes and earthquake hazard mitigation.

The NEHRP Coalition strongly supports the reauthorization of NEHRP, and we urge that the funding authorization levels for the program be increased substantially for the fiscal year 1997 and beyond. Our justification for this request is tied to the urgent need for more rapid utilization of all of the knowledge gained from the Northridge, California, earthquake and the more recent Kobe, Japan disaster. We clearly need to accelerate the implementation of earthquake hazard mitigation throughout the 38 of our states which are at moderate to very high risk.

During the last six years the nation has suffered $10 billion in losses from the Loma Prieta earthquake, and over $20 billion from the Northridge event. These loss rates will certainly increase in future years unless major changes in public policy are made.

In recent years numerous studies and reports have criticized NEHRP for the slow rate of adoption and enforcement of NEHRP research results. We need often to remind ourselves that NEHRP was not initially a mitigation implementation program. It was an earthquake science and technology research and development program. And, the assumption was that states and local jurisdictions would voluntarily and enthusiastically incorporate new mitigation technology, and would push building code changes, would adopt the new codes, and would vigorously enforce them. This clearly has not happened, and in retrospect, the assumption that it would or even could was naive. The problem is that NEHRP did not then, nor does it now have a strong mitigation element within the provisions of the existing program, and can neither establish incentives nor can it establish regulations and enforce them. We will address the issue of incentives in Section II of this testimony.

Many of the studies and reports referred to earlier strongly criticize NEHRP's program management. Clearly, substantial improvement can and should be achieved, but the assumption that "more efficient research" is going to greatly accelerate the rate of mitigation implemention is also naive. We will address the issue of program management in Section III of this testimony.

And in Section IV we will offer a number of specific areas for further technological research.

II. ADOPTION AND ENFORCEMENT OF INCENTIVES

We believe that incentives should be the cornerstone of federal natural hazards mitigation policy-----a top priority and ahead of calls for better strategic planning, interagency coordination and accountability The latter are definitely necessary, but will not accelerate implementation and enforcement at the state and local levels.

If the original assumption on voluntary adoption and enforcement was incorrect, as obviously it was, then any argument which says that the NEHRP program as presently constituted is at fault fails to recognize that NEHRP and its four U.S. government program agencies, (NSF, USGS, NIST, and FEMA,) would individually or collectively have needed authority under NEHRP to establish and enforce implementation regulations or to establish incentives, financial or otherwise, which could have achieved the desired result. Such is not the case, and therefore it is clearly the responsibility of Congress either to establish Federal implementation regulations or financial incentives or both The NEHRP Coalition believes strongly that any combination should be heavily weighted on the side of financial incentives which are certainly the most effective and least objectionable

Earthquakes pose a greater threat of social upheaval and economic losses than any natural disaster to which our nation is subjected. Because these disasters occur infrequently, sustained efforts toward mitigating their consequences is very difficult to achieve. Moreover, earthquake hazard mitigation programs, activities, and responsibilities for taking actions are highly diffused, adding to the difficulty in fostering implementation. The federal government's iniatives for seismic upgrading of buildings which it builds or leases is admirable, but private sector investors and home owners must be induced by other means.

It is recommended that a concerted effort be undertaken to develop financial incentives and to provide for coordinated actions to implement earthquake hazard mitigation actions across jurisdictional lines. In addition, inducements must be developed by working with these jurisdictions to foster better training for building inspectors, better education for the construction trades, and resources for better enforcement. Effective implementation of the technologies developed under NEHRP must be a very high national priority if the social and economic risks of earthquakes are to be reduced to an acceptable level, and financial incentives applicable at all levels are absolutely vital to this process. From our reading of the recently published OTA report entitled "Reducing Earthquake Losses," we believe that OTA confirms this conclusion. That report in its Executive Summary- Policy Options section states:

> "The third type of option includes changes to federal disaster assistance and insurance, regulation, and financial incentives. Such changes are outside the current scope of NEHRP and would represent a significant change in direction for the program. However, **such changes are necessary to yield major national reductions in earthquake risk."**

III. PROGRAM MANAGEMENT ISSUES

From the beginning, NEHRP research of all types, (scientific, engineering, societal,) has been conducted in a collegial, rather than pyramid, fashion with a strong peer review element. And the very nature of NEHRP research has been very heavily "problem focused." "Curiosity-driven research" within NEHRP is virtually non-existent because of the very nature of the subject being addressed. Nevertheless, substantial improvement can be achieved through overarching direction, strategic planning, coordination and accountability, and each of the four program agencies involved directly in NEHRP agrees that this is the case.

A recently completed OSTP study report, (in press,) which resulted from an extensive review of NEHRP by representatives of over twenty federal agencies, including NSF, USGS, NIST, and FEMA, has concluded that the establishment of a program office in FEMA, which would be staffed by personnel from each of the principal program agencies, is the most achievable way to improve program management, and they have further concluded that this is the most cost-effective approach as well.

It has become clear that many federal government agencies in addition to the four directly charged with NEHRP responsibility are involved with earthquake hazard mitigation issues. These agencies should be encouraged to participate in and contribute to the activities of the program office.

Finally, oversight and periodic review of the program office's success should be conducted from the highest levels of government.

IV. TECHNICAL ISSUES

A. RESEARCH SUCCESSES REVEALED BY THE NORTHRIDGE EARTHQUAKE

The Northridge earthquake revealed notable successes in the nation's long-term program to protect itself against disastrous earthquake losses. Building code improvements adopted in California since the 1971 San Fernando earthquake minimized damage and prevented collapse of many commercial, industrial, and residential structures that might otherwise have suffered these levels of damage. Experience in 1971 with the near collapse of the lower Van Norman Dam and subsequent research and evaluation of earth dams resulted in greatly reduced levels of damage to these facilities in 1994. Requirements to retrofit or replace unreinforced masonry buildings in Los Angeles implemented during the past two decades paid off in reduced damage and fewer casualties for those type of structures. Every single bridge and freeway overpass which had been retrofitted survived the earthquake with its full functionality intact. But, perhaps most important, recognition, monitoring, study and public awareness of earthquake hazards in the Los Angeles area resulted in more prompt emergency response and organization than might otherwise have happened. The establishment of the Southern California Earthquake Center as a NEHRP-funded regional earth hazard mitigation resource is an example of this research focus in an area of high risk. These successes are the result of NEHRP support for research in the earth sciences, earthquake engineering, and the social sciences. They are also the result of a team of earthquake specialists educated at universities throughout the United States using NEHRP support. Recent assessment of the probabilities of large earthquakes in the region has focused attention on the very real earthquake risk faced by citizens of Southern California. Continuing actions of this type will be necessary long after the memory of the Northridge earthquake losses have faded away, if we are to protect California, and the other thirty-seven states that are at-risk, from the disastrous social and economic consequences of earthquakes. In this regard, other NEHRP-funded programs such as the Central United States Earthquake Consortium and the National Center for Earthquake Engineering Research have measurably raised earthquake awareness and preparedness in the central and eastern U. S. The NEHRP Coalition strongly urges that the program agencies increase their efforts in the following research, mitigation, and policy areas. The urgent need for accelerated progress in these vital areas more than justifies the increase in funding which we propose.

B. FUTURE RESEARCH NEEDS

Despite the successes noted above, complacency must not be tolerated There is little doubt that the death toll and injury count would have been much higher had the Northridge earthquake occurred later in the morning of January 17. A careful and thorough examination of gaps in our knowledge must be undertaken if we are to succeed in mitigating the earthquake hazard to an acceptable level.

1. ANTICIPATING THE LOCATIONS, STRENGTH, AND THE OCCURRENCE RATES OF FUTURE EARTHQUAKES

The ability to accurately estimate the locations, strengths and occurrence rates of earthquakes is a fundamental requirement for prioritizing mitigation efforts and for reducing the loss of lives and economic disruption that these disasters cause Recent experience -- San Fernando, 1971; Whittier, 1987; Loma Prieta, 1989, Northridge, 1994 -- has shown that moderate earthquakes pose a severe threat to urban populations

Three aspects of this type of earthquake increase the threat: 1) they occur frequently; 2) they tend to occur on many smaller faults that are not capable of producing large or great earthquakes; and 3) they cause intense and extensive damage when they occur in highly populated areas and thus, in sum, affect much wider areas than larger earthquakes. During the past 23 years, moderate earthquakes are estimated to have caused more than $40 billion in losses to just two of our major metropolitan areas - Los Angeles and San Francisco. Other major metropolitan areas in the eastern and central U.S. are also at risk, and losses due to moderate-sized earthquakes must be expected to be even higher in these regions because they are less well-prepared than either Los Angeles or San Francisco. Recognizing that earthquakes having magnitudes in the 6-7 range could occur somewhere in a highly populated area in the U.S. every few years, nationwide priority must be given to identifying the expected locations of these events and projecting the threat which they pose. This information is necessary for setting priorities to reduce losses through retrofitting key structures and essential transportation and utility facilities, for disaster response planning, and as the basis for safe seismic construction of new structures and facilities. Mapping of likely earthquake sources and their expected effects needs to be done for all metropolitan areas that have high earthquake risk. Thirty-eight of our fifty states are at moderate to very high risk from earthquakes that could cause extensive loss of lives, devastating loss of property, and unacceptable economic disruption.

2. ASSURING THE AVAILABILITY OF UTILITIES AND TRANSPORTATION SYSTEMS

Another high priority need, reinforced by recent earthquakes that have struck the urban areas of California, is to develop guidelines for earthquake resistant construction of lifeline facilities, particularly water, gas, and electrical transmission and distribution lines. Closely aligned with these facilities is the transportation system. Currently, two research studies, sponsored by the Federal Highway Administration, are addressing the earthquake vulnerability of highway construction, including bridges, tunnels, retaining structures, slopes and embankments. The first of these projects will develop revised seismic retrofit guidelines and provide cost-effective technologies for improved evaluation and seismic upgrading of the existing highway system. The second project is concentrating on the development of improved seismic design guidelines for water, gas and electrical transmission and distribution systems to assure that these systems are available following an earthquake.

3. UNDERSTANDING FUTURE EARTHQUAKE LOSS POTENTIAL AND STRENGTHENING LOSS MITIGATION

A third priority need is a methodology to reliably determine expected direct losses by class of structure and facility and to project indirect economic losses as well. The earthquakes that have struck the populated Los Angeles and San Francisco metropolitan areas during the past twenty-three years have impacted a broad inventory of structures and facilities. A research effort should be undertaken to learn how this inventory of structures and facilities performed in these recent earthquakes and to use these data in improved methods for assessing the expected losses in future earthquakes. The information developed by such a study could also be used together with results of engineering studies to revise and improve building codes, as the basis for improved insurance administration, for other mitigation actions, and for earthquake response planning

4. EXPANDED MAPPING OF SEISMIC HAZARDS

Building codes and guidelines for seismic design of structures and facilities rely on maps depicting the level of seismic hazard - the level of ground shaking and its probability of being exceeded - to set seismic design criteria. Currently, seismic hazard maps are generalized at a scale representing the entire United States. Because knowledge of the level of seismic hazard is fundamental to providing seismic design, as well as to effective land-use planning and other mitigation actions, there is a strong need to have regional scale maps for regions of high seismic hazard, and detail scale maps for populated urban areas exposed to high seismic risk. As a basis for developing regional and local maps, it is necessary to have more detailed knowledge of the sources of earthquakes and a more complete understanding of the role that local geological and soil conditions have in determining the severity of earthquake motions at a particular location Earthquake induced landslides and various other ground failures are responsible for wide-spread damage and losses. To provide adequate earthquake hazard information requires a commitment to a sustained multi-year earthquake hazard mapping program

5. ASSURING BASELINE EARTHQUAKE RECORDINGS

Recordings of earthquakes on high quality instruments are essential for developing tools and guidelines to mitigate the hazard posed by earthquakes. Two types of recordings are required: recordings on sensitive seismograph instruments designed to record even small earthquakes, and recordings of strong, damaging ground motions on seismographs designed to remain on scale during even the most intense motions. The ability to record and locate small earthquakes throughout the nation is essential in order to identify geological features that are sources of future large earthquakes. A national network of seismographs designed to determine the precise locations of earthquakes is currently being installed. The information from this network will continue to improve our knowledge of the locations and causes of earthquakes and it is essential that this effort be sustained on a long term basis.

There is a need to develop a national network of seismographs to record strong ground motions near earthquake sources. These recordings are essential for developing tools to anticipate the amplitudes and characteristics of structurally hazardous motions from future expected earthquakes. Methods to determine motions from expected future earthquakes are also essential for mapping seismic hazards and providing guidelines for seismic design of structures and lifeline facilities. It is recommended that provisions be made for a sustained national strong ground motion program that would include a national network of recording stations and a national strong ground motion data base. The network should include installations in structures as well as arrays of instruments designed to study the effects of local geology on strong ground motion. The resulting data base should be structured and operated to provide rapid access to high quality recordings by researchers and practitioners engaged in earthquake hazard mitigation activities.

6 DEVELOPING AND VALIDATING COST-EFFECTIVE AND RELIABLE METHODS FOR RETROFITTING EXISTING STRUCTURES

The major risk from earthquakes is the enormous stock of potentially hazardous existing buildings, their contents, and other structures. There have been significant advances in developing and applying various techniques for retrofitting such structures including, for example, base isolation and the use of dampers, as well as structural strengthening and stiffening. Because buildings are being retrofitted, it is often assumed that engineers know exactly how to do the job. However, there simply is not adequate knowledge available to achieve the most appropriate retrofit of a wide range of structural systems in a cost-effective manner and with the assurance of a high probability of success. Part of the problem is an inadequate level of confidence in current methods for predicting the response of existing structures to earthquakes. Such knowledge can only come from an aggressive program of engineering studies, which includes large-scale testing and detailed interpretation of observations during actual earthquakes. Both of these vital studies have been badly underfunded for at least a decade. There are few laboratories that have the capacity to undertake the necessary testing programs, and many of these have not been kept up-to-date in regard to instrumentation and experimental facilities Few opportunities are seized to test structures about to be demolished Although measurements of dynamic response during earthquake shaking have been recorded in a number of buildings, a significant number of these records have not been analyzed adequately. It is necessary to establish a program of upgrading and expanding the laboratory experimental capacity in the nation, and to undertake a prioritized program of studies using these facilities. The ability to perform full-scale testing of selected structures is a vital necessity. The deliverables from such efforts must be proven, effective, affordable retrofit technologies which are ready for market

One of the most significant findings from Northridge is that roughly eighty percent of the economic losses were non-structural. These financial losses resulted from damage to building contents, and to the non-structural elements upon which the buildings functionality depends, such as electric power, gas, plumbing, telephone, and so forth This is an area in which little mitigation research has been done, and in which the pay-back ratio would be very high.

7. DEVELOPING COST-EFFECTIVE SEISMIC DESIGN CODES

A program to develop the knowledge base for the next generation of cost-effective seismic design codes covering all structures and facilities should be undertaken immediately. Many current code provisions are based on the performance of structures in earthquakes that occurred twenty or more years ago and are primarily intended to save lives while giving inadequate emphasis to protecting property or functionality Seismic design procedures must directly link seismic performance requirements to the expected level of earthquake ground shaking if confidence in the safety of a structure is to be achieved. These requirements are then keyed to the various components of the structure and to the importance of that component to the overall safety of the structure. Performance-based seismic design procedures of this type which directly address life-safety, structural integrity, and contents damage, have been applied to the seismic evaluation of certain critical facilities for more than twenty years. With a focused and sustained developmental effort these procedures could be adapted for the seismic design of all structures and facilities, resulting in significant long-term improvements in performance and economic benefits as well as life-safety.

8. MAKING INFORMATION AVAILABLE TO POLICY MAKERS FOR INTERJURISDICTIONAL DISASTER RESPONSE ACTIONS

Recent earthquakes, and particularly the Northridge earthquake of 1994, have revealed a critical gap in timely, accurate information available to decision-makers within the impacted organizations and jurisdictions. An effort was made in response to the Northridge earthquake to introduce advanced information technology and telecommunications to support decision-making. However, to foster wider implementation, improved procedures must be established, and there must be much more advanced preparation and training. The procedures must link decision-makers in real time with information on the earthquake's effect and must particularly accommodate differences in local response capability. It is recommended that a program be supported to establish the information gathering, analysis and dissemination capabilities needed to serve multiple organizations simultaneously. Such a capability must include hardware and software that would enable decision-makers to collect, classify, store, retrieve and exchange relevant information using existing telecommunications technology and systems. These systems must be interactive to permit continuous inflow of information as the response to a disaster unfolds. Finally, provisions must be made for ongoing development and for training of officials responsible for implementing the system during an earthquake disaster.

9. MAINTAINING AN EFFECTIVE RESEARCH INFRASTRUCTURE

It is shortsighted to believe that our knowledge base is sufficiently complete and that the only task facing NEHRP is to implement currently available information. A recent congressional initiative to eliminate or cut back severely the USGS External Research Grants Program was clearly ill-advised. That badly under-funded program forms the very underpinning upon which the nation's earthquake hazard mitigation efforts are based.

Completion of each of the tasks outlined in this testimony is dependent on an active research program in the earth sciences, earthquake engineering, and in the social sciences. However, our infrastructure in these fields is under stress because it is under-funded and ill-equipped. Successes to date have been achieved in spite of a decline in funding and other resources. If the earthquake risk is to be reduced in a timely manner, innovation must be encouraged. New risk reduction strategies are required that are increasingly reliable and cost-effective. This will require a sustained effort that systematically addresses these issues. It also needs to be funded at a level commensurate with the intellectual challenge that is involved. Funding levels for NEHRP should reflect the consequences of ignoring the risk and must ultimately be based on the financial benefit to the nation from reducing the huge disaster relief expenditures which inevitably follow each major earthquake. Societal costs of earthquakes can, and must, be reduced by leveraging significantly smaller expenditures that can be put in place in advance of the next destructive earthquake.

Mr. BAKER. Thank you. Dr. Jordan.

STATEMENT OF DR. THOMAS JORDAN, CHAIR, DEPARTMENT OF EARTH SCIENCE, MASSACHUSETTS INSTITUTE OF TECHNOLOGY, CAMBRIDGE, MASSACHUSETTS

Mr. JORDAN. Thank you, Mr. Chairman. I guess I am here because I have participated in NEHRP as a researcher funded through the National Science Foundation, but I would also point out that I am familiar with its overall goals and achievements through my experience in several advisory capacities which include the current chairmanship of the National ResearchCouncil Committee on Seismology and membership on the Advisory Panel of the recent OTA study.

Although the successes of NEHRP in basic and applied research are generally well regarded and usually not disputed, it has recently become very popular to criticize NEHRP for what it has not done in implementing current knowledge about earthquake hazards through more aggressive mitigation programs. But, as you've heard from previous speakers today, the problems of implementation are largely issues for state and city governments, which must assess and respond to earthquake risks, engineering problems and community priorities that are highly variable from one part of the country to another.

The degree to which the Federal Government can, and should, attempt to force particular mitigation strategies on local populations is highly controversial. Moreover, it's clear that to be really effective, more aggressive Federal policies will have to be backed by levels of funding that far exceed the size of the current NEHRP.

But, I am not an expert in these issues, so I will instead focus my remarks on a much less controversial aspect of NEHRP, which is the status and prospects of basic and applied research on the science of earthquakes and the Federal Government's role in supporting this research. My primary point is this. Regardless of what level the Federal Government involves itself in the implementation process, the most effective foundation for continued national efforts in earthquake hazard reduction is a vigorous federally-funded and coordinated program of basic and applied research directed towards a better understanding of earthquakes and earthquake related damage.

Earthquakes are a very complex phenomenon involving deep-seated geological processes about which we still know very little. But, almost all will agree that NEHRP's investments in long-term earthquake research have been hugely successful and that they are paying out substantial short-term practical dividends in several areas of public concern.

Great improvements in seismic hazard mapping and long-term earthquake forecasting have been made using the new techniques of paleoseismology and global positioning system geodesy. And, these have identified major—have identified higher levels of seismic risk in areas like the Pacific Northwest and the Wasatch Front in Utah.

Armed with this information, some communities have enacted more comprehensive hazard mitigation programs, including land use planning and zoning provisions, more stringent building codes and seismic retro-fit programs. In high risk areas of California, the prioritizations needed to implement the seismic retro-fit programs, which are always very resource-limited, are being aided by microzonation studies which provide a rational basis for the targeting of the most vulnerable structures.

The data derived from a new generation of broad-band, high-dynamic range seismographic instrumentation are providing engineers with better criteria for designing earthquake-resistant structures, including the time histories that take into account the phase as well as the amplitude of ground shaking. Post-earthquake emergency response has been enhanced by the ability to rapidly collect, process and distribute seismic information to potential users.

Earthquake early warning systems are under development that may be able to immediately detect and broadcast when a major earthquake has occurred, thereby alerting critical facilities that potentially destructive seismic waves are on the way.

NEHRP's accomplishments also include the establishment of regional working groups, comprised of earth scientists, earthquake engineers and local officials, which act to coordinate and publicize mitigation-related activities. One of these is the Southern California Earthquake Center, whose tasks include the construction of regional seismic hazard maps, the formulation of realistic earthquake scenarios and the processing of real time earthquake information, as well as doing fundamental research on regional tectonic processes and earthquake dynamics.

Built into the SCEC program is a vigorous set of activities aimed at public education and community outreach, as well as interfaces to the relevant state and local agencies.

Now, the new data being provided by geological field investigations and by the new types of seismic and geodetic instrumentation, that have been installed under the auspices of the NEHRP program, is already stimulating additional advances in earthquake science and its application to hazard reduction. For example, global positioning system measurements, in the near future, will yield more qualitative estimates of earthquake risk in the eastern continental interior, where historical seismicity is significant but tends to be distributed in ill-defined zones characterized by low and previously unobserved strain rates.

Dynamical studies of complex systems of interacting faults will improve the ability to anticipate the sequencing of earthquake activities in very active regions. There are many other examples I could go into, but perhaps the potential for long-term research gains are best illustrated by the problem of earthquake prediction.

Now, a few would question the notion that if earthquakes could be accurately predicted in terms of their times, locations and magnitudes then much could be done to reduce their potential for damage. But, no practical scheme for this type of short-term earthquake prediction has yet been discovered.

And, we must recognize that useful prediction algorithms are, at best, years away and, at worst, completely unattainable. However, it is not actually known whether earthquakes are predictable or not, even in principle.

There has been some progress in basic research, however, that I think is cause for renewed optimism that some earthquakes, at least, may be predictable or, at least, in principle. And, I would argue that NEHRP should intensify the integrated, multidisciplinary efforts aimed at evaluating earthquake predictability in a variety of geological settings.

Research centers like SCEC should be established in other areas of high seismic activity and the instrumental networks for close-in monitoring of this activity, both seismic and geodetic, should be upgraded and expanded. New technologies like dense arrays of continuously monitoring GPS stations should be deployed.

Field observations by teams of geologists should be supported with adequate funds for extensive mapping and trenching. Theoretical work on the physics of the earthquake rupture process and the interactions with fluid systems in the crust should be accelerated through the increased use of high-performance computers.

And, finally, considerably more emphasis should be placed on the study of earthquakes occurring outside the borders of the United States, since these studies can considerably increase the knowledge of different earthquake types.

The first 17 years of NEHRP have been an unequivocal success in terms of the technical areas the program was intended to address. And, these research-based accomplishments should, in the future, generate returns with much greater dollar value in the form of reducing earthquake losses.

Given the increasing threat that earthquakes pose to our population centers, there is a clear argument for a modest but steady increase in the NEHRP budget over the next three years that will allow the program to take advantage of the outstanding research opportunities that I have listed here, as well as to expand its programs for implementing mitigation strategies.

Thank you.

[The prepared statement of Dr. Jordan follows:]

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Submitted to the Subcommittee on Basic Research, Committee on Science, U.S. House of Representatives, for Hearing on the National Earthquake Hazard Reduction Program, to be held on October 24, 1995.

Mr. Chairman and Members of the Subcommittee on Basic Research:

My name is Thomas H. Jordan, and I am the Robert R. Shrock Professor and Head of the Department of Earth, Atmospheric and Planetary Sciences at the Massachusetts Institute of Technology. Since receiving my Ph.D. in geophysics from the California Institute of Technology in 1972, I have taught and supervised research in geophysics and seismology on the faculties of Princeton University, the Scripps Institution of Oceanography, and MIT. I have participated in the National Earthquake Hazard Reduction Program (NEHRP) as a researcher funded through the National Science Foundation, and I am familiar with its overall goals and achievements through my experience in several advisory capacities. For the past three years, I have chaired the Committee on Seismology, a standing committee of the National Research Council that provides the federal government with advice about seismological research and practice. I participated in the National Earthquake Strategy Workshop held in June, 1994 by the Office of Science and Technology Policy, and I was a member of the Advisory Panel for the 1995 Office of Technology Assessment study of NEHRP, *Reducing Earthquake Losses*. I also serve as a member of the Advisory Council of the Southern California Earthquake Center (SCEC).

Earthquakes cause more loss of life and damage to property than any other type of natural disaster, and the rapid expansion of large urban infrastructures is steadily increasing the threat of earthquakes to human society. The cost of U.S. earthquake damage during this century is estimated to be forty billion (constant 1994) dollars. It is striking that more than two-thirds of this total resulted from two of the most recent earthquakes, the 1989 Loma Prieta and 1994 Northridge events, both of which were over an order of magnitude smaller than the great 1906 San Francisco earthquake. During the next several decades it is likely that large earthquakes will strike one or more urban centers in the United States, inflicting a significant number of human casualties and costing at least tens if not hundreds of billions of dollars in damages. (For comparison, the losses from the recent earthquake near Kobe, Japan, are estimated to be more than 5,500 lives and $200 billion.) Although earthquakes cannot be controlled, they can be understood, and their disastrous effects can be mitigated by a wide variety of actions taken by an informed populace.

Earthquakes are a very complex phenomenon involving deep-seated geological processes about which we still know very little. My testimony today will focus on what has been, and I believe should continue to be, the central tenet of NEHRP: *The most effective foundation for continued national efforts in earthquake hazard reduction is a vigorous, federally funded and coordinated program of basic research directed towards a fundamental understanding of earthquakes and earthquake-related damage*. In making this argument, I will address four questions: What has been progress in earthquake science during the two decades of the NEHRP? How has this basic research contributed to practical earthquake mitigation strategies? What are the prospects for further breakthroughs in earthquake science? What new opportunities in earthquake science should the future NEHRP address?

Progress in Earthquake Science under NEHRP. Prior to the initiation of NEHRP in 1977, the data on earthquake phenomena were rudimentary. Most seismic sensors were analog devices that could only record signals over a restricted range of frequencies and would go off-scale—"hit the stops"—during earthquakes of even moderate size; only a few close-in readings of large earthquakes had been obtained from special sensors designed to measure very strong ground motions. Very little was known, therefore, about the violent ground motions that damage buildings and other structures during earthquakes. Almost all seismograms were recorded on paper, requiring a time-consuming hand-transcription to digital form before any computer analysis of the signals could be done. Indeed, the computing capabilities of even the most well equipped laboratories were primitive by today's standards, so that only the simplest aspects earthquake ruptures and seismic wave propagation could be analyzed with quantitative techniques. At that time, the new theory of plate tectonics had already provided a gross understanding of where to expect most large earthquakes (on the boundaries between two moving plates), but the detailed nature of these boundaries, which can extend over broad zones in continental regions like the western U.S., had not been explored. Moreover, plate tectonics gave very little insight into the causes of earthquakes at locations far away from plate boundaries—places like Charleston, South Carolina, and New Madrid, Missouri, which were the sites of huge earthquakes during the nineteenth century. Almost nothing was known about the occurrence of prehistoric earthquakes, so very little could be said about how frequently big earthquakes might happen on major faults like the San Andreas in California. The U.S. Geological Survey had pioneered ground-based geodetic techniques to monitor the buildup of strain on faults (which is eventually released by earthquakes), but the collection of geodetic data on the San Andreas and a other fault systems was restricted by the high expense and limited range of geodetic measurements. Hence, earth scientists were in a poor position to advise engineers and the general public about where, how often, and how strong ground shaking would be; they could not provide rapid and accurate assessments of what had happened during a large earthquake, nor could they quantitatively assess the aftershock risks immediately following such events.

Research in earthquake science done under the auspices of NEHRP and other federal programs has changed all of this. Seismic networks have been upgraded with high-performance instruments having very broad bandwidth and high dynamic range, capable of accurately recording both very weak and very strong seismic signals. In some regions like Southern California, advanced communications now deliver these data to high-performance computers rapidly enough to allow seismologists to locate and describe an earthquake within the first few minutes after its occurrence, and then to transmit the results in near-real time to local authorities, to lifeline engineers and critical-service companies, and even to private citizens. An entirely new technology based on the Global Positioning System (GPS) has been developed that is capable of precise, continuous monitoring of strain buildup across well-defined, narrow fault zones as well as broader, more diffuse belts of deformation. With these data, geophysicists have improved their forecasts of which faults will produce large earthquakes and how often such ruptures will occur.

Long-term forecasts have also been refined by the new discipline of paleoseismology. Through careful mapping, trenching, and dating of features within a fault zone, geologists have been able to estimate the ages and magnitudes of major prehistoric earthquakes and thus obtain invaluable constraints on the probable magnitude and recurrence intervals of future earthquakes. The geological structure and seismic potential of the plate-boundary deformation zones in the western U.S. and Alaska are now much better understood. For example, NEHRP-sponsored structural mapping, geodetic measurements, and paleoseismology studies have shown that the Wasatch Fault in Utah and the fault systems along the Washington and Oregon coasts are capable of generating much stronger earthquakes than indicated by the historical seismicity. Geologists have identified the subsurface structures responsible for intraplate earthquakes in the Mississippi Valley and along parts of the Atlantic margin; they have also uncovered a new class of buried faults—the so-called "blind thrusts" responsible for the 1994 Northridge and 1987 Whittier Narrows earthquakes—which pose a significant (and previously underestimated) threat to Los Angeles and other parts of the western United States. Seismologists have developed more sophisticated and successful models of fault friction and earthquake rupture dynamics, and they have achieved a nascent understanding of how the rupture of one fault can enhance or reduce the chances of an earthquake happening on another nearby fault.

Contributions of Earthquake Science to Hazard Mitigation. Recent reviews, including the OTA study, have criticized NEHRP for being ineffectual in translating these enormous gains in our knowledge of earthquake phenomena into practical strategies for mitigating earthquake hazards. It has been argued that NEHRP has suffered from poor leadership and the lack of effective coordination among the participating agencies. While these criticisms are based on some truth, they tend to have a superficial, inside-the-beltway concern for the top-down aspects of agency management, and their prominence in the recent reviews and congressional testimony has not, in my opinion, been balanced by adequate assessments of the steady, bottom-up progress towards NEHRP's goal of reducing earthquake hazards. (The paucity of internal programmatic assessments is, of course, among the failures assignable to the participating agencies.)

The facts are clear: NEHRP's investments in earthquake research are already paying out substantial practical dividends in several areas of public concern. Consider, for example, the improvements in seismic hazard mapping and long-term earthquake forecasting derived from paleoseismology and GPS measurements of strain accumulation. As mentioned above, studies using these techniques have established the Wasatch Front and the Pacific Northwest as areas of high earthquake potential, and they have confirmed relatively high intraplate deformation rates suspected for the New Madrid region of Missouri, Kentucky, and Tennessee. Armed with this information, communities in some of these areas have enacted more comprehensive hazard-mitigation programs, including land-use planning and zoning provisions, more stringent building codes, and seismic retrofit programs. In high-risk areas of California, the prioritizations needed to implement the resource-limited seismic retrofit programs are being aided by microzonation studies, which combine detailed mapping of near-surface geology with seismographic recordings of local earthquakes and probable scenarios of future ruptures to predict where anomalously strong shaking, liquifaction, and ground failure might occur. They provide a rational basis for the targeting the most vulnerable structures for the earliest retrofits in programs where the resistance to retrofit proposals can be severe and the available dollars are always much smaller than the projected needs.

The data derived from broad-band, high-dynamic range seismographic instruments during recent California earthquakes are providing engineers with better criteria for designing earthquake-resistant structures, including time-histories that take into account the phase as well as the amplitude of the ground shaking. Post-earthquake emergency response has been enhanced by the ability to rapidly collect, process, and distribute seismic information to potential users through the CUBE system in Southern California and the REDI system in Northern California. Earthquake early warning systems are under development that can immediately detect and broadcast when a major earthquake has occurred, thereby alerting critical facilities to expect potentially destructive seismic waves. This notification can be done up to tens of seconds prior to the wave arrivals, enough time to initiate automatic emergency procedures.

NEHRP's accomplishments also include the establishment of regional working groups, comprising earth scientists, earthquake engineers, and local officials, which act to coordinate and publicize mitigation-related activities. One of the largest and most successful groups is the Southern California Earthquake Center, founded in 1991 and supported jointly by the U.S. Geological Survey and the National Science Foundation. SCEC sponsors research by scientists from the USGS and a number of U.S. academic institutions, and it engages them in a highly coordinated, multidisciplinary study of earthquake hazards in Southern California. Its research tasks include the construction of seismic hazard maps for the entire region, the formulation of earthquake scenarios for high risk areas such as Los Angeles and San Bernadino, and the processing of real-time earthquake information, as well as fundamental research on regional tectonic processes and earthquake dynamics. Built into the SCEC program is a vigorous set of activities aimed at public education and community outreach, as well as interfaces to the relevant state and local agencies.

Prospects for Earthquake Science. The new data now being collected by geological field investigations and by high-performance seismic and geodetic instrumentation will stimulate additional advances in earthquake science and its application to hazard reduction. For example, GPS measurements will yield more quantitative assessments of earthquake risk in the eastern continental interior, where the historical seismicity is significant but tends to be distributed in ill-defined zones characterized by low (and previously unobserved) strain rates. Dynamical studies of complex systems of interacting faults will improve the ability to anticipate the sequencing of earthquake activity in very active regions.

Although there are many other examples, the potential for long-term research gains are perhaps best illustrated by the problem of earthquake prediction. This is highly controversial topic in earthquake science. Few would question the notion that, if an earthquake could be accurately predicted in terms of its time, location, and magnitude, then much could be done to reduce its potential for damage. But no practicable scheme for this type of short-term earthquake prediction has yet been discovered; indeed, it is not known whether earthquakes are predictable, even in principle. In the mid-1970's, there was a heady optimism among some geoscientists that earthquake prediction was just around the corner, and this spirit contributed to the establishment of NEHRP. Unfortunately, the theories that underlay this optimism were poorly supported by actual seismic data, and their applicability to the earthquake prediction problem was quickly proven (by NEHRP-sponsored research) to be illusory. More recently, it has begun to be appreciated that the earth's crust may, in many regions, maintain itself in a state very close to failure, so that a big earthquake might result at a more-or-less arbitrary time from a cascade of events nucleated by a very small initial earthquake. Based on this thinking (which is again theoretical), some geophysicists have argued that the short-term prediction of large earthquakes is essentially impossible, because the information that a major rupture is about to happen is not encoded into the system. These ideas are consistent with a notable lack of systematic short-term precursors for a series of moderate-to-large earthquakes recorded during the last ten years by near-field strainmeters in California and Japan.

There is, however, considerable cause for renewed optimism regarding the prospects of earthquake prediction. First, the advances in long-term earthquake forecasting will permit the deployment of various instruments in regions where the probabilities for capturing major earthquakes are greatest. Obtaining very close-in recordings of such events is critical for evaluating more precise prediction schemes. Second, statistical algorithms have been developed by Russian scientists for intermediate-term earthquake prediction (i.e., on time scales of months to years) that are based on the subtle, large-scale behavioral patterns now thought to be characteristic of complex systems approaching the point of failure. These algorithms are still being refined and evaluated, but preliminary results suggest that they may have some predictive skill. Finally, there have been a series of observations in the U.S. and elsewhere which suggest that the preparation zone for major earthquakes may be large enough to generate detectable precursors hours, days, or even months prior to the event. One of the most exciting studies was recently published in *Science* by Bill Ellsworth of the USGS and Greg Beroza of Stanford University, who used data from the new generation of high-performance seismographs to measure the properties of a distinctive, but previously unstudied, seismic nucleation phase. (These phases could not be detected on older instruments, because they were driven off scale by events of even moderate magnitude.) Ellsworth and Beroza show that the size and duration of the nucleation phase scale with the eventual magnitude of the earthquake. If this conclusion survives the intense scrutiny it is now receiving, then the information that a major rupture is about to occur *is* encoded into the system, and the prospects are brighter that at least some earthquakes might be short-term predictable.

The Future of NEHRP. At present, we must simply admit that we just do not know which types of earthquakes, if any, are short-term predictable. Moreover, we must recognize that the useful prediction algorithms are at best years away and, at worst, completely unattainable. But our society cannot afford a leisurely, unfocused approach to the difficult questions surrounding the issue of earthquake prediction. The new NEHRP should intensify the integrated, multidisciplinary efforts aimed at evaluating earthquake predictability in a variety of geological settings. Research centers like SCEC should be established in other areas of high seismic activity, and the instrumental networks for close-in monitoring of this activity should be upgraded and expanded. New technologies like dense arrays of continuously recording GPS stations should be deployed. Field observations by teams of geologists should be supported with adequate funds for extensive mapping and trenching. Theoretical work on the physics of the earthquake rupture process and its interactions with fluid systems in the crust should be accelerated through the increased use of simulation codes now installed on high-performance computers. And more cooperation with research efforts in other at-risk countries should be fostered through substantial U.S. participation in programs like the U.N.-sponsored International Decade of Natural Disaster Reduction. Considerably more emphasis should be placed on the study of earthquakes occurring outside the borders of the United States, because such studies can substantially increase the diversity of earthquake types for which good data sets are available.

The first 17 years of NEHRP have cost the American taxpayer just under $1.3 billion. NEHRP has been an unequivocal success in the technical areas it was intended to address, and it will generate economic returns with a much greater dollar value in the form of reduced earthquake losses. Given the increasing threat that earthquakes pose to our population centers, there is a clear argument for a modest but steady increase in the NEHRP budget over the next three years to allow the program to take advantage of the outstanding research opportunities, as well as to expand its programs for implementing mitigation strategies.

Mr. BAKER. And, thank you. Dr. Somerville.

STATEMENT OF DR. PAUL SOMERVILLE, ENGINEERING SEISMOLOGIST, WOODWARD-CLYDE FEDERAL SERVICES, PASADENA, CALIFORNIA

Mr. SOMERVILLE. Thank you. My name is Paul Somerville. I work for a geotechnical engineering consulting firm.

I was a member of the Earthquake Engineering Research Institute's delegation to a conference in Osaka, Japan when the Kobe earthquake struck about 15 miles away from where the conference was being held. The title of the conference was the "Fourth U.S./Japan Workshop on Urban Earthquake Hazard Mitigation."

So, I just want to focus my remarks on one topic, which is the Kobe earthquake and what it means for us in the United States. To do that, I want to use the viewgraphs.

And, let me begin with the Northridge earthquake, which one might think of as being a comparable event. But, I want to show you the ways in which it is not comparable.

This is a map of the Los Angeles region. And, this shows three things.

First of all, this rectangle is the fault that ruptured during the Northridge earthquake. It's about 14 miles beneath Northridge and about four miles beneath the mountains here north of the San Fernando Valley.

The second thing the map shows is in these hash regions are places where the dense urban zones are in the L.A. region. This is the San Fernando Valley, Santa Monica, west Los Angeles and downtown Los Angeles.

The third thing it shows are these dots. And, these dots represent the peak ground velocity recorded during the earthquake.

Now, you can see from this map that the size of the dots in the dense urban region is quite small. The big ground motions were recorded up here, more or less out of harm's way, north of the San Fernando Valley.

And, they are big there because the rupture propagated from depth up towards the surface. And, this is where the freeways fell down and steel buildings were severely racked in this locality.

But, by and large, you would say this was a near miss. Now, in contrast with that picture from Northridge, this is the picture from Kobe.

It's showing the dense urban region, which is this hash zone here. The fault now is a vertical fault that is shown by these lines here.

And, Kobe is this region here. And, the dots, again, are showing how strong the ground motion was.

Now, in this case, you can see that the largest recorded peak velocities were in the dense urban region. And, they were big, because the rupture propagated directly into this dense urban region.

The estimated losses from this earthquake are about $125 billion. And, from Northridge, about $25 billion. So, it makes a factor of about five difference or so in loss.

Now, if you turn this map around a little bit like this, it bears an uncanny resemblance to Oakland, California.

[Laughter.]

Mr. SOMERVILLE. And, the point I want to make is that there are many regions in the United States that are just as vulnerable, if not more so than Kobe, because these kinds of earthquakes actually occur more frequently than we think they occur in Kobe. So, the issue is that we may be facing losses in individual earthquakes in the United States that may amount to $125 billion.

I have addressed in my testimony all the questions that were raised to be addressed in the invitation that I received in my invitation to appear here. But, I don't have time to go into all of those. I will just answer one of them.

Before I do that, let me quickly show this figure. This is from the Architectural Institute of Japan.

This is describing some damage statistics in the Kobe earthquake. The top figure is for concrete structures and the bottom figure is for steel structures.

The color code is sort of like a building tag. Blue is slight damage or no damage. Green is minor damage. Yellow is moderate damage. And, red is collapse or severe damage.

And, the three histograms are for different time periods. Before 1971 is here. Then, 1972 to 1981 is here. And, then 1982 and beyond is here.

Now, these divisions are based on changes and upgrades in building codes in Japan. And, you can see there is a dramatic improvement in the performance of these structures as we progress towards the present time.

In other words, building codes in Japan have been extremely effective in reducing the ratio of severe damage or collapsed buildings, as you see in the vanishing or rapidly decreasing amount of red in these figures. So, I think this is a very clear lesson which may be applicable to us, too, that building codes really can have a very important effect on reducing damage.

And, finally, I want to answer just one of the questions that was posed in my invitation to address this Subcommittee. And, it is. Does the Federal Government need to put more teeth into earthquake hazards reduction? If yes, what is the best way to achieve results?

And, so my answer is. Yes, more teeth are needed in earthquake risk reduction. The experience of the Kobe earthquake of January 17, 1995 suggests that the United States may incur direct economic losses of $100 billion or more from moderate magnitude earthquakes occurring within urban communities, in addition to loss of life and indirect economic losses.

I do not think that the resources that are committed to earthquake risk reduction in the United States are commensurate with this very high level of risk to life and economic health. The only comparable external threat to our society, short of war, is AIDS. To date, the direct cost of dealing with AIDS in the United States has been $75 billion.

So, what are the best ways to achieve results?

Mr. BAKER. Let me assure you that all of your questions will be answered as you submit your testimony.

Mr. SOMERVILLE. Okay.

Mr. BAKER. So, you don't have to show them to us.

Mr. SOMERVILLE. I have just a few more.

Mr. BAKER. You don't have a map of the Loma Prieta earthquake to show where the fault is in relation to the population center?

Mr. SOMERVILLE. No. But, if I did, it would show that most of the damage occurred about 90 or so kilometers away from the epicentral region of that earthquake.

So, there was what I would call a "far miss" where the earthquake was located quite remotely from the epic region but still very severe damage was done with collapsed bridges and so forth.

Let me quickly finish here. I think these are important points.

The best way to achieve results are to introduce legislation that mandates or provides financial incentives for the adoption of codes and the implementation of mitigation measures. And, that's the same topic that Dr. Anderson addresses.

Provide better coordination of applied research and involve researchers and practicing professionals jointly in focused applied research projects like the SAC joint venture. Fund activities such as seismic microzonation that identify zones of special vulnerability to seismic hazards and thereby help to prioritize hazard mitigation work.

Fund studies aimed at understanding the causes of the large amount of damage caused by the Kobe earthquake and whether such damage would occur during earthquakes in the United States. There are two more to go.

Provide better mechanism for the development of building codes, which are revised every three years. The appropriate development of these codes should be less dependent on the voluntary contribution of free time by busy practicing professionals, like me, and more dependent on a rigorously reviewed and adequately funded process involving the collaboration of practicing professionals and researchers. Future codes need to be performance based and address non- structural as well as structural damage.

Finally, provide adequate funding for pure research, applied research and development and implementation. The NEHRP program consists of a very capable and committed community of professionals, but their productivity is severely limited by a shortage of funds to support research and its implementation.

Thank you.

[The prepared statement of Dr. Somerville follows:]

SUBCOMMITTEE ON BASIC RESEARCH

COMMITTEE ON SCIENCE

U.S. HOUSE OF REPRESENTATIVES

HEARING ON THE NATIONAL EARTHQUAKE HAZARDS REDUCTION PROGRAM

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Testimony prepared by

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This testimony is in the form of responses to questions, reproduced in boldface, contained in the hearing charter.

What has been learned from the Northridge and Kobe earthquakes?

Kobe

The 1995 earthquake ruptured directly into and underneath downtown Kobe. The focussing effect caused by rupture propagating toward Kobe produced almost the most severe ground shaking levels possible, causing effects that resemble a worst case earthquake scenario. The toll from the Kobe earthquake was 5,368 dead and 26,815 injured. It is estimated that 144,032 buildings were destroyed by ground shaking and 7,456 buildings were destroyed by fire. The number of homeless people requiring shelter was approximately 300,000, which is 20% of the population of Kobe. Current estimates of direct losses in this city of 1.5 million people lie between $100 to $150 billion. This does not include the loss of building contents, or indirect economic losses due to dislocation caused by the earthquake.

The fault on which the Kobe earthquake occurred had been clearly identified as a seismic hazard by earth scientists in the 1970's. Government agencies and the public alike were surprised by the earthquake, however, reflecting the conventional wisdom that earthquakes don't occur in the Kansai District (Kobe, Osaka and Kyoto). It appears that the national government was preoccupied with the seemingly larger and more imminent seismic hazard in and near Tokyo (where very damaging earthquakes occur about once every one hundred years), and ignored the hazard in the Kansai district where the frequency of occurrence of very damaging earthquakes may be closer to once every one thousand years.

About one-third of all low rise residential and commercial and one-sixth of all mid rise buildings located within 3 miles of the fault in Kobe collapsed or were severely damaged. Levels of damage to reinforced concrete and steel buildings were dramatically lower with successive upgrades in building codes in 1971 and 1981, demonstrating the effectiveness of improvements of buildings codes as a long term mitigation measure. The performance of bridges was worse than that of buildings, because ductile design procedures of the kind introduced for buildings had not been implemented for bridges. Many older bridges collapsed catastrophically and many new bridges were severely damaged. The Kobe earthquake shows that even in a technologically advanced and seismically vulnerable country like Japan, engineers are just beginning to learn how to effectively design structures to withstand earthquakes.

Differences between Kobe and Northridge

The Kobe earthquake was similar to earthquakes that occur in California, and the largest ground motion levels recorded in Kobe are similar to those of the Northridge earthquake. What then explains the much larger level of damage in Kobe ($100 to $150 billion) than Northridge ($25 billion)? While low-rise residential buildings in Kobe may have been weaker than their counterparts in Northridge, most engineers consider that other structures in Kobe were of comparable strength to those in Northridge. The much larger level of damage in Kobe was probably caused by the very large ground motion levels in the dense urban region, due to the rupture of the earthquake directly into this region.

As shown in Figure 1, the largest peak ground velocities recorded from the Kobe earthquake were in the dense urban region. Equally large peak ground velocities were recorded during the 1994 Northridge earthquake, as shown in Figure 2. However, the Northridge earthquake ruptured updip and to the north, so the largest ground motions occurred on the northern fringe of the dense urban region, not at its center. Although the Northridge earthquake occurred beneath an urban region, almost all of the faulting occurred at depths greater than 5 miles, and the majority of multi-story buildings in the San Fernando Valley were at least 10 miles from the fault due to their location in the southern part of the Valley. With the principal exception of the freeway bridges in the northern San Fernando Valley, large structures in the Los Angeles region were not subjected to the large near-fault ground motions that downtown Kobe experienced.

Can a Kobe damage scenario occur in the United States?

I think so, but this question should be the subject of urgent and intensive research, because an affirmative answer would have important implications for policy decisions concerning the reduction of earthquake risk in the United States. The conditions that gave rise to the large ground motions in Kobe exist in San Diego, San Bernardino, downtown Los Angeles, West Los Angeles, and Oakland, and were presumably present in the 1906 San Francisco and 1933 Long Beach earthquakes, to name just a few locations in just one state. Unlike the Kobe earthquake, recent earthquakes in California have not ruptured directly into dense urban regions, but instead have occurred on the fringes of dense urban regions. Like the Kobe earthquake, most have occurred at favorable times of day (very early morning) and under favorable wind conditions (preventing the spread of fire).

One of the important lessons from the Kobe earthquake is that devastating earthquakes can occur in regions of relatively low seismic activity, like most of the United States east of the Rocky Mountains. These regions tend to be especially vulnerable to earthquakes because of the low perceived level of hazard.

A more detailed discussion of the implications of the Kobe earthquake for seismic hazard mitigation in the United States is provided in Structural Engineers Association of Northern California (1995).

Northridge

The small number of building collapses during the Northridge earthquake signals the success of structural engineering in meeting the goals of current building codes, which are to prevent loss of life by preventing collapse. But the huge economic loss of $25 billion shows that the goals of the code must be broadened beyond the protection of life safety to include reduction of economic losses. The earthquake engineering community is already embarking on this task of developing "performance based design," the goal of which is to prevent economic losses and in some cases prevent interruption of operation of the facility. To achieve this objective, structural engineers recognize that they need to go back to basics and learn how to understand and predict the performance of buildings during earthquakes. They also have to place more emphasis on how to reduce losses due to non-structural damage (i.e. architectural and contents damage),. which exceeded the losses due to structural damage in the Northridge earthquake. This will require the adequate funding of researchers and design professionals working together in applied research projects like the SAC Joint Venture Project described below.

Did Northridge shed any light on the effectiveness of the NEHRP programs?

Yes. When the magnitude 6 Whittier Narrows earthquake occurred on a blind thrust fault beneath Los Angeles in 1987, little was known about the kind of fault on which it occurred because these faults do not reach the earth's surface. Since then, much progess has been made by NEHRP-funded earth scientists in understanding blind thrust faults. However, the fact that the 1994 Northridge earthquake occurred on a blind thrust fault that had not been identified illustrates the need for ongoing research.

As another example, the strong ground motions recorded during the Northridge earthquake were 50% larger than those predicted based on strong motion data recorded during past earthquakes. But methods for predicting strong ground motions based on seismological models, developed by NEHRP-funded seismologists, showed that the recorded ground motions were predictable from such models. However, much remains to be learned about whether the localized zones of concentrated damage caused by the Northridge earthquake are attributable to local geological conditions, and if so how these local conditions amplified the ground motions.

The brittle failures that occurred in the moment frame connections of steel buildings during the Northridge earthquake was a surprise to most structural engineers. The FEMA-sponsored SAC Joint Venture Project, whose objective is to reduce seismic hazards in steel moment frame buildings in the aftermath of the Northridge earthquake, is a model of how applied research projects involving the collaboration of researchers and practicing professionals should be conducted. It is a joint venture between the Structural Engineers' Association of California, the Applied Technology Council, and the California Universities for Research in Earthquake Engineering. Interim guidelines for the evaluation, repair, modification and design of welded steel moment frame structures are provided in a report released in August 1995 (SAC Joint Venture, 1995).

Is NEHRP research user driven?

Some NEHRP research is user driven. An example is the National Earthquake Ground Motion Mapping Project sponsored by the USGS, which provides input into the development of seismic provisions for national building codes. Another is the SAC Joint Venture Project mentioned above. However, much NEHRP research is driven more by the interests of researchers than by the needs of users, and consequently much of it does not have and may never have the potential for practical application. Also, the NEHRP agencies that fund research are not currently well set up to manage applied research. One way of enhancing the relevance of research and enhancing its implementation is to involve more practicing professionals in applied research following the model of the SAC Joint Venture.

Should the NEHRP program emphasize short-term, applied research such as microzonation rather than improving basic earth science knowledge?

It needs to do both: to improve basic earth science knowledge and to support applied research. There is a danger that basic research will be neglected if too much emphasis is placed on short-term applied research. I expect that what we learn from basic research in the next few decades will be much more useful for seismic hazard mitigation than what we know now. At the same time, I think that microzonation is a potentially very effective short-term tool for risk mitigation.

Microzonation is the mapping of seismic hazards, expressed in relative or absolute terms, on an urban block-by-block scale, based on local conditions (such as soil types) that affect ground shaking levels or vulnerability to soil liquefaction. It is motivated by the observation, common to all earthquake disasters, that severe damage tends to be concentrated in discrete zones which may be separated by relatively unscathed regions. By identifing the localities within a region which are most subject to seismic hazards, it provides an effective means of prioritizing mitigation actions which may otherwise be financially or administratively unmanageable in scope.

There has been criticism that many of the technologies and practices developed have not been implemented and that research is far ahead of implementation.

It may be that much research lacks practical relevance, but I do not think that research is far ahead of implementation. On the contrary, in many areas the technical. questions are beyond our present capacity to give useful answers, and research is only beginning to produce findings that can be implemented. Some of these basic research problems are: What is the physics of earthquakes, and how can we predict earthquakes and their effects? How can we realistically model the behavior of structures during earthquakes? How can we economically reinforce existing structures? How can sociological knowledge be used to enhance the effectiveness of earthquake preparedness, earthquake response, and the implementation of mitigation measures?

Is laboratory research adequate for testing welded steel structures?

See testimony by Dr Dan Abrams.

There has been criticism that NEHRP lacks clear goals and strategies, that the program is disjointed, and that each agency is pursuing uncoordinated activites based primarily upon its own agency mission.

The OSTP report addresses many of the organizational issues raised here. I think that one of the best ways to have better integrated and implemented research is to use the kind of collaboration between university researchers and practicing professionals that forms the basis of the SAC Joint Venture Project.

Does the Federal Government need to put more teeth into earthquake hazard reduction. If yes, what is the best way to achieve results?

Yes, more teeth are needed in earthquake risk reduction. The experience of the Kobe earthquake of January 17, 1995 suggests that the United States may incur direct economic losses of $100 billion dollars or more from moderate magnitude earthquakes occurring within urban communities, in addition to loss of life and indirect economic losses (see preceding discussion). I do not think that the resources that are committed to earthquake risk reduction in the United States are commensurate with this very high level of risk to life and economic health. The only comparable external threat to our society, short of war, is AIDS. To date, the direct cost of dealing with AIDS in the United States has been $75 billion.

The best ways to achieve results are:

Introduce legislation that mandates or provides financial incentives for the adoption of codes and the implementation of mitigation measures. See testimony by Dr Thomas Anderson.

Provide better coordination of applied research, and involve researchers and practicing professionals jointly in focussed applied research projects like the SAC Joint Venture.

Fund activities such as seismic microzonation that identify zones of special vulnerability to seismic hazards and thereby help to prioritize hazard mitigation work.

Fund studies aimed at understanding the causes of the large amount of damage caused by the Kobe earthquake, and whether such damage could occur during earthquakes in the United States.

Provide better mechanisms for the development of building codes, which are revised every three years. The appropriate development of these codes should be less dependent on the voluntary contribution of free time by busy practicing professionals, and more dependent on a rigorously reviewed and adequately funded process involving the collaboration of practicing professionals and researchers. Future codes need to be performance based, and address non-structural as well as structural damage.

Provide adequate funding for pure research, applied research and development, and implementation. The NEHRP program consists of a very capable and committed community of professionals, but their productivity is being severely limited by a shortage of funds to support research and its implementation.

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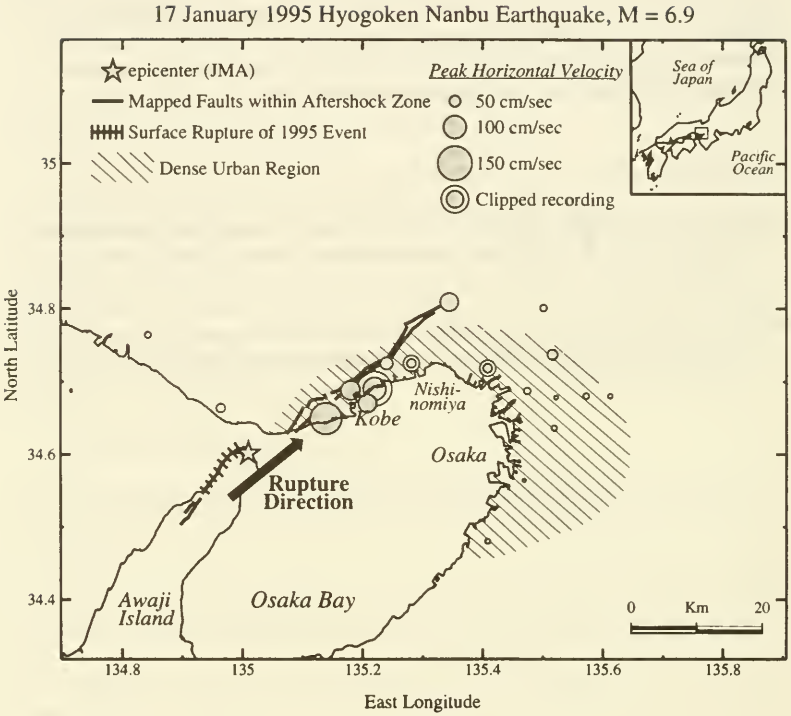

Figure 1. Map of the Kobe region showing the location of the fault that caused the earthquake, the strength of the shaking (in cm/sec) at strong ground motion recording sites, and the location of the dense urban region. This map shows that the dense urban region of Kobe experienced the strongest ground motion recorded during the earthquake.

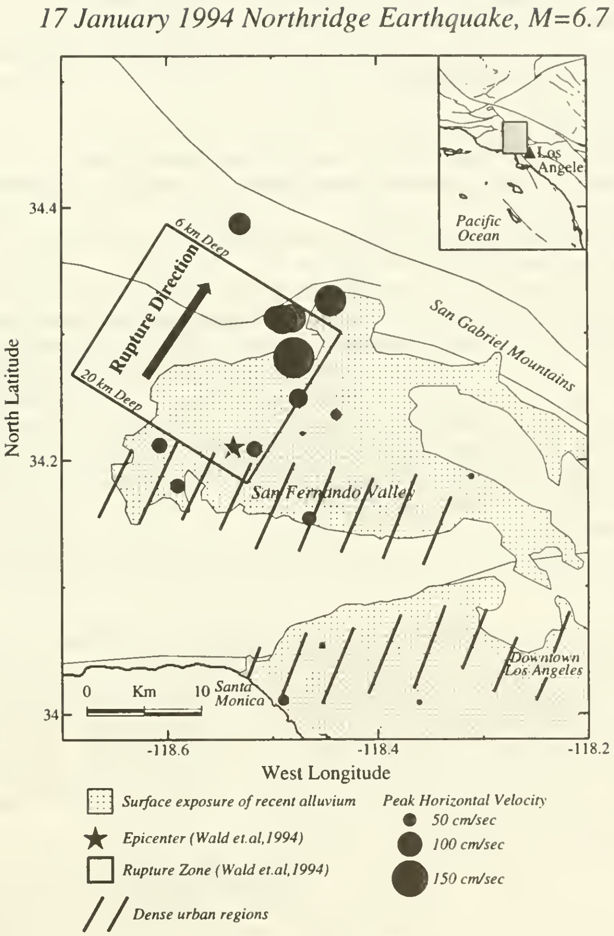

Figure 2. Map of the Los Angeles region showing the surface projection of the buried rectangular fault plane that caused the earthquake, the strength of the shaking (in cm/sec) at strong ground motion recording sites, and the location of dense urban regions. This map shows that the dense urban regions of Los Angeles escaped the strongest ground motion recorded during the earthquake.

Mr. BAKER. And, thank you very much. I am going to turn this over to Mr. Geren for questions and the Chair for a moment.

Mr. GEREN. All right. I thank you, Mr. Chairman.

You know, Dr. Somerville, I think it would tell us a lot about how you feel about your career as to whether you consider being in Kobe when the earthquake hit as to have been very good luck or very bad luck.

[Laughter.]

Mr. SOMERVILLE. From my point of view, good luck.

Mr. GEREN. Well, that's commendable to have that dedication to your life's work.

I appreciate the testimony of everyone. This has been very enlightening and helpful to all of us.

You raise so many different issues. And, I know you have all submitted written testimony that will be reviewed by the Committee.

And, it's hard to know where to focus with my questions. But, I'm trying to figure out where we should spend limited resources.

And, we are not going to have the funds to do everything that we should do. And, certainly, when you consider the magnitude of the threat, as Dr. Somerville has outlined—I thought it was particularly interesting, your comparison to the AIDS threat and getting us to think outside of the box, so to speak. That was very thought- provoking.

But, if you were to have an additional $60 billion to—$60 million to—

[Laughter.]

Mr. GEREN. Well, $60 billion would still be peanuts, wouldn't it, Dr. Somerville, when you consider the threat?

But, the $60 million that Dr. Abrams talked about earlier, and he talked about the need, the way he thought it should be spent. And, I would just ask each one of you to suggest to us where you would spend those additional funds if we did have the opportunity to spend that limited amount of money, considering the size of the threat and the problem.

Mr. SOMERVILLE. Well, let me begin. The point I just made was that I feel that there are many dedicated professionals in earthquake hazard mitigation in the United States, but everywhere I look I see people whose effectiveness and productivity is being limited by the amount of funding that they are able to receive to pursue research and implementation that they want to follow.

So, I think that, at least, provide adequate funding to the program that exists now. And, then, beyond that, I would look down the list that I just read and think about some of the other suggestions that have been presented this afternoon.

Thanks.

Mr. GEREN. Thank you. Dr. Jordan.

Mr. JORDAN. Let me comment on this. Obviously, it's not hard to think of ways to spend money, but in terms of the research activities, I sit on the Advisory Council of the Southern California Earthquake Center.

I don't actually participate in the Center, but I do get to view its activities. And, I have been very impressed by how this rather coordinated activity and scientists, engineers and public officials can really contribute to an understanding of earthquake hazards and can go a long way towards informing the public about these hazards in an area like Southern California.

And, it seems to me that this type of coordinated activity could be usefully erected in other regions of the country, because so often these programs are different from region to region.

Along with that, it seems to me that there needs to be more resources put into the instrumentation that is capable of recording earthquakes and understanding earthquake phenomena. An example of this would be the—there are proposals for putting in very dense arrays of modern geodetic instruments based on the global positioning system that would go a long way towards allowing us to understand the types of strain accumulation, the strain buildup, that eventually is released in earthquakes in very complex geological settings like Southern California.

And, investments in these types of activities—in this type of instrumentation would certainly be very worthwhile.

Mr. GEREN. Thank you. Dr. Anderson.

Mr. ANDERSON. I would suggest that the correct answer to the question of allocation of the new found money would be to match it towards what you had set up within a strategic planning process. If one had gone through and developed a strategic plan, worked with all the stakeholders in adopting priorities, you then would have some sense of how you allocate new resources.

It's tempting to want to place it into the experimental community where the facilities have eroded through the years. But, I think unless we can look at all of the needs together and have a sense of establishing overall priorities—perhaps the priorities this year will be different than they might be in years past or in years in the future, but I think we need to establish those priorities within that strategic thinking and that's where the money should be placed.

Mr. GEREN. When you say "stakeholders," who all would you—

Mr. ANDERSON. Well, I would say the stakeholders are all of those who are engaged in the experimental enterprise. They are also the design professional, public works officials, emergency preparedness individuals, the social scientists who study the behavior of individuals, Federal agencies.

I think everyone who has a stake in either identifying the hazard or mitigating its risk.

Mr. GEREN. Thank you. Dr. Kiremidjian.

Ms. KIREMIDJIAN. Thank you. I concur, to some extent, with Dr. Anderson that we need to look at where the needs are the greatest.

Although I have to say that testing, renewing our test facilities, is something that needs to be looked at much more carefully. Over the next years, if we do get sustained funding, I think if we identify our priority where the greatest needs are that we can start funding those areas that are in the greatest need for improvement or we need to concentrate our efforts in those areas.

And, certainly testing is one of them. But, it's not the only answer.

Together with testing, for example, I would say there is a need for more advanced numerical methods in earthquake engineering methods for analyzing structures that have been developed over the years but need to be improved. And, we also need to think in terms of how we translate all the findings that we do into the practicing community.

Funding also needs to be concentrated in a variety of the socioeconomic issues. I think we need to look at the broad picture.

So, in that sense, I would say I concur with Dr. Anderson that they already have spent a considerable amount of time thinking about the global issue, the global issues that relate to NEHRP. And, we should really review that plan and find out what are the greatest needs and where we should be putting our money and over what period of time.

Mr. GEREN. Thank you, Mr. Chairman. And, I thank all the witnesses. I want to thank all the panelists today.

This has been a very thought-provoking hearing. And, I, again, commend Chairman Schiff for initiating it.

Let me just make one last observation, if I could. All of you have provided us great insights from your perspective and every panel, at least some members of it, have mentioned the implementation gap.

And, as a public policy body, the Congress is going to have to work to set up incentives that somehow take the great work of people in the technical fields and get those into play. And, that's not an easy task. It's, politically, very controversial.

And, just one anecdote. In an area I represent, we sustained around a $1 billion disaster last spring in a big storm. It was the twelfth biggest in history.

But, because we were so well insured, we weren't entitled to disaster relief. So, you have an incentive—had we been less well insured for that disaster, Federal funds would have flowed into our area.

The fact that it was the sort of disaster that we happened to be well insured for, we didn't qualify for it. So, we have a perverse incentive built into this system.

And, the politics are such that every local community knows that if the disaster is big enough that we will be there regardless of what sort of bad decisions preceded that disaster that allowed them to find themselves in such a pickle. But, as public policy folks, we need to do something to make sure that the great work that ya'll have done and will do is somehow put into practice.

And, if nothing else, that we don't do something to discourage it, which is what our current policy towards disaster relief does.

Thank you, Mr. Chairman.

Mr. BAKER. Peter Geren, thank you very much for being here, too. Dr. Bartlett.

Mr. BARTLETT. Thank you so much. I have a couple of brief questions.

I think I noted a common theme in all of your testimonies. And, it began with Dr. Kiremidjian.

You indicated that this organization was doing both basic research—you referred to it as research and basic research—and implementation. You indicated it was about a one-third/two-third split in the dollars that were available for that.

And, you said that this was a shortsighted policy. Shortsighted because the split is wrong or because you are asking the same organization to do both basic research and implementation?

Ms. KIREMIDJIAN. Actually, perhaps I should qualify that my comments were based on an impression that we may be emphasizing a lot more implementation and a lot less research in future years. And, what I would like to see is continue the emphasis on basic research and that we should not stop doing basic research.

I think the current split is perhaps adequate. From my perspective, I would like to see more basic research done, because there is a great deal of value in basic research.

But, I also recognize the importance of implementation in this particular case. And, my comments were not so much referring to a particular split.

Mr. BARTLETT. But, you were referring to the balance between basic research and—

Ms. KIREMIDJIAN. What I would like to say is that, again, it is an impression that is created among the research community that NEHRP is trying to push forward and push towards implementation rather than towards research. And, perhaps it is a wrong impression.

I don't really know. But, it is the impression that many of my colleagues seem to share, that as we push more towards implementation that funding for implementation will have to be taken from research.

And, as such, I think what we are trying to avoid is—we are trying to say is that research should continue, at least, at the rate it has been going until now. We have made some very important contributions in research.

And, we couldn't possibly start implementing prudent policies if we don't know enough about the earthquake phenomenon. If we don't know about how structures behave, we couldn't possibly improve our building codes.

And, that's the general impression that is being created. And, thus my comments were in response to that impression.

Mr. BARTLETT. So, you are making a plea for adequate funding of basic research?

Ms. KIREMIDJIAN. Correct.

Mr. BARTLETT. Okay. Thank you very much. I have some personal background in both the basic area and the applied area, having been actively involved in publications and ending up being awarded 20 patents.

And, I have a personal bias. And, I think it's frequently difficult and not very productive to require basic researchers to be involved in implementation.

That's a general feeling I have across here. But, is this a specialized area where this generalization wouldn't apply?

And, can we require here the basic researchers to become implementors without seriously impacting the quantity and quality of their basic research?

Dr. Anderson, or anyone else who wishes to reply?

Mr. ANDERSON. I would suggest that the researcher not try to succeed by pushing his technology out in the market. We would prefer to have a market pull and a market that was eager to have those technologies and that knowledge.

And, that isn't the case now, because this information is going out to the market. Much of it is free. And, it's just simply not being used.

And, that's why I was suggesting that the Coalition feels that incentives are needed. I don't see the incentives as requiring new money.

I think we need some reform in how we go about paying the societal costs for earthquakes. They eventually will cost us something. If we can do something beforehand to prevent the loss, we will reduce that cost.

And, some of the incentives that I think are appropriate are either all hazards or certainly earthquake hazard risk-based insurance. That definitely accounts for individuals who mitigate that risk, both in the structure and in the contents.

I think another form of incentive needs to be mortgage rates tied to your activities on mitigation. So, if you mitigate the earthquake risks, you ought to qualify for a more attractive mortgage rate.

Bankers would be happy with that. You are protecting their investment.

I think another form of incentive would be investment tax credits, where you recognize mitigation. All of these are immediate.

They affect the decision-maker right away. He begins to see a benefit now rather than waiting years down the line.

Mr. BARTLETT. You are a good free-market supporter.

Mr. ANDERSON. And, a fourth one is education. Many of us have mentioned it. Many of the members have mentioned education.

Education, education, education. If we continue to constantly but gently educate our public that it is in their best interest to protect their own well- being and their own property, that they then can reduce the impact of the earthquake and they can be functioning members of the community very quickly.

Education does work. It has caused many of us to quit smoking. It has caused many of us to eat better. It has caused many of us to exercise more.

And, I think that's the kind of behavior change we are looking for.

Mr. BARTLETT. But, don't you think government is so much smarter and we ought to be making decisions for these people?

[Laughter.]

Mr. BARTLETT. I'm only joking, of course.

Mr. BAKER. That was the last Congress, Mr. Bartlett. Thank you very much.

[Laughter.]

Mr. BAKER. I want to thank the panel, too. You have done a tremendous job.

And, as we move into work on the reallocation for NEHRP, we will use this information, especially the ones in the reports and your testimony.

One last question seems to be in order. Are there other countries that are as advanced in the studies of earthquakes as we are? And, should we be doing more with them?

I know Japan and Russia have all had serious earthquakes. Armenia had a tremendous—are you familiar with that one?

Ms. KIREMIDJIAN. Yes, I am. I did visit Armenia about six months after the earthquake. And, I also visited a number of locations.

I would say, in many ways, Japan—I wouldn't exactly say that it's more advanced than we are. I think our knowledge—having worked with a number of Japanese colleagues, I would say we are probably equal partners.

They seem to be better at implementing some of their findings in earthquake-resistant design codes than we are. We seem to be a little bit slower.

However, I would say that our knowledge in many areas is at least as good if not better than Japan. As I said, we are probably behind in implementation. And, it probably has to do with the kind of society that we are.

If you are comparing us with Russia and other places in the world, by no means do they even come close to the level of understanding, to our building techniques, to our level of implementation, to our response and mitigation strategies. I don't think there is a comparison.

We stand well ahead of the rest of the world.

Mr. BAKER. Thank you.

Mr. JORDAN. Mr. Baker, if I may make a comment on that?

Mr. BAKER. Sure.

Mr. JORDAN. I would answer your question with a resounding yes. Obviously, in terms of the leverage we might get in cooperating with other countries like Japan, which are investing as much as this country is or more in terms of earthquake hazard mitigation, we obviously can gain.

But, it should be pointed out that another major gain is that earthquakes occur all over the world all the time. If you are in one particular country, you are only going to see some fraction of those.

Earthquakes that occur in other regions can teach us a lot about earthquakes that occur in the United States. And, cooperative programs with other nations is one way to help get that information and allow us to use it more effectively.

Mr. BAKER. Great. Thank you.

Mr. ANDERSON. Perhaps I would add a caveat to that. I think we need to understand that cooperative research has been intrinsic to the earthquake engineering enterprise ever since the United States hosted the first World Conference on Earthquake Engineering in 1954.

And, we know that the community of fellow researchers and practitioners is everywhere. Perhaps if we could improve, it would be that following destructive earthquakes anyplace in the world that we are better able to leave a team there, not just for a few days or a few weeks while they do a damage reconnaissance survey but rather stay there longer and better understand the lessons.

How did it influence codes? How did it influence building practices? And, then we could bring that knowledge back.

So, we do well. We can do better.

Mr. BAKER. That's interesting. Okay.

Ms. KIREMIDJIAN. I think the Kobe earthquake is a clear example of where we could learn a lot. There are many similarities between Kobe and the California codes.

And, I think the teams that have gone to Kobe and have investigated the disaster have come back with very valuable lessons.

Mr. BAKER. Okay.

Mr. SOMERVILLE. If I may add a few comments about Kobe, as well. Number one, after Kobe, the Japanese have been looking to FEMA as a model for how to handle emergencies. I think that's an important fact.

And, I think the area in which we are maybe stronger than Japan is that we, I think, are better at interdisciplinary communication and interaction through organizations like the Earthquake Engineering Research Institute; whereas, I think in Japan, people tend to be a little bit more compartmentalized. And, so I think that the open communication that occurs in the United States earthquake engineering community, usually in volunteer time on evenings and weekends, I think really provides a lot of benefit.

And, I think we should feel good that, for example, in Northridge we found that a lot of the things that we have been doing work fairly well. Thank you.

Mr. BAKER. Thank you. And, I want to thank the panel again and especially to members, Vern Ehlers and Roscoe Bartlett and Peter Geren for sticking around through this hearing.

Thank you all for today.

[Whereupon, the hearing is concluded at 3:43 p.m., Tuesday, October 24, 1995.]

[The following material was received for the record:]

UNITED STATES DEPARTMENT OF COMMERCE
National Institute of Standards and Technology
Gaithersburg, Maryland 20899-0001

November 22, 1995

The Honorable Steve Schiff
Chairman, Subcommittee on Basic Research
Committee on Science
House of Representatives
Washington, DC 20515-6301

Dear Mr. Chairman:

Our response to your questions of November 10, 1995, is enclosed. We will be happy to provide any further information needed.

Sincerely,

Richard N. Wright

Richard N. Wright, Director
Building and Fire Research Laboratory

Enclosure

NIST

RESPONSES TO QUESTIONS FROM THE BASIC RESEARCH SUBCOMMITTEE

Question 1:

Is it feasible for NIST or some other NEHRP agency to do cost benefit analyses on building codes?

It is feasible for NIST to do cost benefit analyses of the seismic provisions of model building codes. NIST has both the engineering expertise and the economics expertise to perform such a study. It would best be performed in conjunction with private sector experts in design and construction.

In the development of the NEHRP Recommended Provisions, such a study was performed with support both from NIST and from the private sector. This study compared new building designs with and without the use of seismic provisions and concluded that adequate seismic design rarely increased the overall cost by more than 2% as compared to no consideration of seismic loads.

Question 2:

Does NIST's building code research address nonstructural damage?

Because damage to nonstructural components in earthquakes often costs as much as damage to the structure itself, NIST has two projects underway which specifically address nonstructural damage from earthquakes. The first project, *Performance of Non-Structural Components*, is concerned with the development of recommended provisions for the seismic design of the components within and above suspended ceilings. These nonstructural components include such elements as suspended acoustical tile ceilings, fire sprinkler systems, light fixtures and heating, ventilating and air conditioning (HVAC) ducts. This project has three phases: literature review, analytical modeling and shake table testing. Work in the current year will focus on analytical modeling and formulation of design recommendations. If funding is available for subsequent work, experimental studies will be conducted to validate the recommendations.

The second project, *Seismic Performance of Cladding Systems*, focuses on the evaluation of the seismic performance of exterior architectural cladding elements during the Northridge earthquake, and the development of energy dissipating cladding systems for seismic retrofit or for design of new buildings. Although cladding elements are not specifically designed for seismic forces, they participate in resisting lateral loads as they deform with the framing system. Some cladding systems sustained damage during the Northridge earthquake, particularly those on steel frame structures. The seismic performance of buildings could be improved by utilizing effectively the cladding system to dissipate energy. These systems can conceivably be applied to both new construction and seismic retrofit. This project first documented the performance of architectural cladding during the Northridge and other earthquakes. An experimental investigation making use of existing test fixtures at Georgia Institute of technology will now study the performance of energy dissipating cladding systems. The next phase will determine the contributions of cladding to the stiffness and damping of the overall structural system. The end result of this project will be seismic design guidelines for building cladding systems.

Question 3:

How does NIST promote the implementation of improved seismic design and construction practices?

NIST supports many ongoing efforts to promote the implementation of improved design and construction practices. These efforts fall into the following three areas.

Interagency Committee on Seismic Safety in Construction - In accord with P.L. 101-614, NIST provides the chairman and technical secretariat for the Interagency Committee on Seismic Safety in Construction (ICSSC) through which 30 Federal agencies concerned for seismic safety collaborate to develop and incorporate earthquake hazard reduction measures in their programs. The Federal Emergency Management Agency (FEMA) funds the work of the ICSSC secretariat. The work of the ICSSC over the past several years has concentrated on the development of two Executive Orders and related standards. Executive Order 12699, signed by the President in January of 1990 addresses the seismic safety of new Federal buildings and requires the Federal government to follow appropriate seismic design and construction standards in the design and construction of all new Federally owned, regulated and assisted buildings. Executive Order 12941, signed by the President in December of 1994, addresses the seismic safety of existing Federal buildings and adopts life safety standards as the minimum acceptable for the evaluation of existing Federal buildings and the strengthening of those found deficient.

Following the President's issuance of Executive Order 12699, *Seismic Safety of Federal and Federally Assisted or Regulated New Building Construction*, NIST and ICSSC undertook a number of activities in support of the Executive Order's implementation. These included translating the *NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings* into language suitable for incorporation into the national buildings codes, issuing a Recommendation that the seismic provisions of the then current editions of the three model building codes are appropriate for implementing the Executive Order and publishing *Guidelines and Procedures for Implementation of the Executive Order on Seismic Safety of New Building Construction*, ICSSC RP-2.1a, to assist the agencies in developing their programs in response to the Executive Order.

The ICSSC continues in its efforts to promote the Executive Order and to assist agencies in developing their specific programs. In May 1995, a report was issued which compared the most recent editions of the

International Council of Building Officials (ICBO) Uniform Building Code, the Building Officials and Code Administrators International (BOCA) National Building Code, the Southern Building Code Congress International (SBCCI) Standard Building Code, the Council of American Building Officials (CABO) One- and Two-Family Dwelling Code, and the American Society of Civil Engineers (ASCE) 7-93, *Minimum Design Loads for Buildings and Other Structures*, to the 1991 edition of the National Earthquake Hazards Reduction Program (NEHRP) Recommended Provisions. Also in May 1995, the ICSSC issued a Recommendation, based on the results of this study, which stated that the seismic provisions of the current editions of the three model building codes, as well as ASCE 7-93 and Appendix, are appropriate for implementing the Executive Order. This recommendation is very important for cost-effective seismic safety. The designer of a Federal, or Federally-assisted or regulated building, can use the model building code familiar to the locality without incurring either the expense or the possibility of misunderstanding involved with use of an unfamiliar special Federal seismic requirement.

Damage from recent earthquakes has made it apparent that existing buildings built before the use of modern seismic codes are at much higher risk during an earthquake. However, there previously have been few requirements to upgrade any of these buildings and there have been no building codes or standards for the rehabilitation of these buildings. The Federal government, under the direction of NIST and the ICSSC, has taken a lead role in the identification of this situation and the development of the tools to tackle this problem. Public Law 101-614 called for the ICSSC to work with appropriate private sector organizations in the development of standards for assessing and enhancing the seismic safety of existing buildings constructed for or leased by the federal government. The standard, RP-4, *Standards of Seismic Safety for Existing Federally Owned or Leased Buildings*, was published in February 1994. The Law also called for the President to adopt the standards by December 1, 1994. Executive Order 12941, *Seismic Safety of Existing Federally Leased or Owned Buildings* was signed by the President on December 1, 1994. This Executive Order is the implementing authority for the RP-4 Standard and requires all federal agencies to use the RP-4 Standard as a minimum when evaluating or rehabilitating existing buildings for seismic safety.

In addition to its use as a minimum standard, RP-4 contains certain trigger situations which require an agency to evaluate and develop a plan for the mitigation of any building found to be seismically deficient. These triggers include a change in the use of the building, other upgrades being performed on the building, and the determination of the building as representing an "exceptionally high seismic risk." This provides a passive plan to reduce the seismic risk in Federal buildings. In order to determine the full extent of the level of seismic risk in existing Federal buildings a more pro-active plan must be put into place. For this reason, Executive Order 12941 tasks all affected Federal agencies to develop a full inventory of their owned and leased buildings, and to develop estimates of the costs expected to bring this inventory up to a level of acceptable seismic safety. The information collected through this effort will be used to present to Congress recommendations for an economically feasible plan to mitigate the existing Federal inventory.

The Executive Order states that the details for the inventorying and cost estimating effort are to be published by the ICSSC within one year of the signing of the Order. In response, the ICSSC is developing two documents. The Guidance Document provides the recommended methodology for collecting and reporting inventory and cost estimate information. It was published as *ICSSC Guidance on Implementing Executive order 12941 on Seismic Safety of Existing Federally Owned or Leased Buildings*, RP-5, in October 1995. The Handbook suggests detailed techniques for developing this information and will be published as *How-to Suggestions for Implementing Executive order 12941 on Seismic Safety of Existing Federal Buildings, A Handbook* before December 1, 1995.

Presentation of Research Results to the Design and Building Code Community - The final stage of much of NIST's earthquake engineering research is the adoption of pertinent research results into building codes and standards so that the knowledge learned in the laboratory can be put to use in design and construction. Specific ongoing projects which are focused on recommendations for standards are *Performance Requirements for Passive Energy Dissipation Systems for Buildings and Lifeline Structures*, and *Seismic Performance of Precast Concrete Connections*.

Passive energy dissipation systems, specifically seismic isolation, have been demonstrated in recent earthquakes as an effective tool in reducing the level of response in structures during strong earthquake ground shaking. Testing is an essential element in the design and construction of seismically isolated structures. Testing of the isolation system prior to installation is required by each of the existing building codes that deal with the design of isolated structures. However, standards do not yet exist for conducting these much needed tests. Therefore, procedures and results are subject to considerable variability. NIST has completed the development of guidelines, a pre-standard, for testing of isolation systems. The guidelines address pre-qualification, prototype and quality control testing. The guidelines were developed in collaboration with an oversight committee of experts and with inputs from about 40 workshop participants from the research and practice communities. Work now continues to develop a detailed experimental and testing plan, to conduct tests according to the procedures established in the Guidelines, and to report on the adequacy and feasibility of the guideline test procedures based on the observations and experience gained in the test program.

While the NIST guidelines have been developed with a great deal of input from the base isolation community, they do not constitute a formal consensus standard. NIST has proposed to ASCE that the NIST guidelines be used as the basis for the developing an American National Standard Institute (ANSI) national consensus standard for testing of base isolation systems. ASCE has accepted the proposal and formed a standards committee. NIST serves as the committee's technical secretariat. In this way, technology developed at NIST is being transferred into engineering practice.

The objective of the Precast Concrete Connection Project is to develop building code provisions for moment resistant precast concrete beam-column connections. These are based on design guidelines derived from experimental work jointly sponsored by NIST and the private sector and completed at NIST. The inclusion of provisions in national building codes is essential to acceptance of precast concrete in seismic zones. NIST has presented these guidelines to the Structural Engineering Association of California (SEAOC) and the American Concrete Institute (ACI) committees for their consideration for adoption into building codes and standards. Such adoption would allow the use of this new form of connection to gain the advantages of quality and economy of precast construction while assuring seismic safety.

Participation in Code and Standards Organizations and Committees - NIST participates actively in over 100 national and international standards development activities for construction and fire. NIST also provides volunteer leadership to major standards organizations such as the International Standards Organization, the American Society for Testing and Materials, the American Concrete Institute (ACI), the American Institute of Steel Construction (AISC), the American Society of Civil Engineers (ASCE), and the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE). Examples of NIST staff's participation relevant to the earthquake engineering program are:

- Dr. H. S. Lew, Chief, Structures Division/Building and Fire Research Laboratory (BFRL), serves on ACI Committee 318, Standard Building Codes and AISC Specification Committee on Steel Construction

- Dr. Richard Marshall, Leader, Structures Evaluation Group, Structures Division/BFRL, serves on ASCE 7, Wind Loads Task Committee and ASCE Executive Committee of Structural Standards Division

- Dr. Riley M. Chung, Leader, Earthquake Engineering Group, Structures Division/BFRL, serves on ASCE Committee on Natural Disaster Reduction, and as vice chair of ASCE Organizing Committee for the 1996 International Conference on Natural Disaster Reduction, and as chair of Special Session on Lifelines at the 11th World Conference on Earthquake Engineering, June 1996.

This participation allows NIST to understand needs for the development of improved codes and standards in the earthquake engineering field and to respond to the needs.

321 Lincoln Avenue
Takoma Park, MD 20912

November 21, 1995

Representative Steve Schiff
Chairman, Subcommittee on Basic Research
Committee on Science
U.S. House of Representatives
2320 Rayburn HOB
Washington, DC 20515-6371

Dear Representative Schiff:

Thank you for the opportunity to testify at the October 24, 1995 hearing on the National Earthquake Hazards Reduction Program (NEHRP). This letter is in response to additional questions submitted by Members of the Subcommittee.

Q: In light of OTA's findings with respect to the limited role the federal government plays in implementation of hazard mitigation programs, would you suggest changes in the way this aspect of NEHRP is funded? In other words, would you advocate spending more or less of NEHRP's resources on this endeavor?

A: As OTA's recent report, *Reducing Earthquake Losses,* notes, about 80% of NEHRP's funds are used for research, and about 20% for implementation programs. Given the large gap between the state of the knowledge and the level of implementation of this knowledge, in my personal opinion it would be appropriate to consider shifting more funds to implementation. One reasonable goal would be to split the funding evenly: 50% for research and 50% for implementation.

Q: Countries all over the world have facilities and programs for earthquake research and hazards mitigation. Given the trend toward international cooperation in science programs and on science issue, shouldn't the Unites States aggressively pursue cooperative research with these countries? Instead of building new research facilities in the U.S., as some have called for, couldn't we achieve the same goals by entering into cooperative agreements to use existing facilities in the United States?

A: International cooperation is, of course, desirable, but is limited by the variations in construction practices and materials across countries. Japan, for example, uses different building practices, materials, and codes; so in many cases the results of their engineering research are not directly applicable to the U.S.

Please let me know if I can be of any further assistance.

Sincerely,

Paul S. Komor

Paul S. Komor, Ph.D.

NATIONAL SCIENCE FOUNDATION
4201 WILSON BOULEVARD
ARLINGTON, VIRGINIA 22230

November 24, 1995

The Honorable Steve Schiff
Chairman, Subcommittee on Basic Research
Committee on Science
House of Representatives
Washington, D.C. 20515-6301

Dear Mr. Chairman:

Enclosed is the response to the questions you posed in your letter of November 10, 1995. I would be happy to answer any other questions that might arise.

Sincerely,

Joseph Bordogna
Assistant Director for Engineering

RESPONSE TO QUESTIONS TO NSF FROM
THE HOUSE SUBCOMMITTEE ON BASIC RESEARCH

QUESTION 1.

How does NSF ensure that research and technological developments in the NEHRP program are disseminated to the state and local level?

ANSWER

Working in partnership with the other NEHRP agencies, one of the principal ways NSF facilitates the dissemination of new research results and technologies to state and local officials and decision makers is through the support of information clearinghouses. Such activities include the two branches of the National Information Service for Earthquake Engineering at the University of California at Berkeley and the California Institute of Technology, the Information Service at the National Center for Earthquake Engineering Research at SUNY-Buffalo, and the Natural Hazard Information Center at the University of Colorado. These clearinghouses make needed knowledge produced by NEHRP and other sources available to state and local officials and other users through an assortment of library services and the distribution of publications and computer programs. NSF also supports conferences and workshops for the purpose of informing various decision makers, such as those in California's Office of Emergency Preparedness and the Central U.S. Earthquake Consortium, about new research results. Additionally, with our encouragement NSF grantees frequently provide professional advice directly to state and local officials, as was the case when officials were developing seismic building codes in New York City and Connecticut.

QUESTION 2.

What are NSF's goals for NEHRP?

ANSWER

The primary goal of NEHRP is to reduce the nation's future losses, including casualties, property damage and social disruption, from earthquakes. Each NEHRP agency has a role to play in achieving this goal. NSF's role is to support multidisciplinary research which has the potential for leading to the discovery of new knowledge and technologies that can be used to further sound mitigation and preparedness actions throughout the nation. Under NEHRP, NSF has also been given major responsibility for supporting the education and training of future generations of knowledge producers and users as well as overseeing the health of the research physical infrastructure, including experimental research facilities. Consistent with the outlook of its NEHRP partners, NSF's vision is that the program will continue to produce the requisite knowledge and further the needed actions at the federal, state and local level to enable the nation to remain a world leader in this area.

QUESTION 3.

Should the NEHRP program include cost-benefit analyses of building codes?

ANSWER

NEHRP has shown an interest in analyzing the benefits and costs of building codes and other approaches to mitigation. Over the years, NSF has indicated to the research community, for example researchers with expertise in economics, its willingness to consider funding projects that would advance knowledge in this area. Among the NEHRP agencies, NIST plays a key role in the analysis of building codes and standards and the development of model seismic provisions. Consistent with this role, NIST oversaw an analysis of the NEHRP Recommended Provisions which demonstrated the relatively modest increased costs involved in including seismic design requirements for new buildings.

FLUOR DANIEL

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November 22, 1995

The Honorable Steven H. Schiff, Chairman
Subcommittee on Basic Research
Committee on Science
B-374 Rayburn House Office Building
United States House of Representatives
Washington, D.C. 20515

Dear Congressman Schiff:

Attention: Mr. Chuck Cadena

Thank you for the occasion to respond on behalf of the NEHRP Coalition to additional questions raised by members of the Subcommittee regarding the National Earthquake Hazards Reduction Program. My responses to the four questions are attached.

We welcome and appreciate the opportunity to work with you and your committee in the future.

Sincerely,

Thomas L. Anderson
Regional Manager
Fluor Daniel Technologies

Attachment

cc: R. J. Swain

RESPONSE BY THOMAS L. ANDERSON TO ADDITIONAL QUESTIONS SUBMITTED BY MEMBERS OF THE SUBCOMMITTEE ON BASIC RESEARCH
November 22, 1995

Q1: In your testimony you mentioned the need to upgrade earthquake engineering testing facilities and laboratories and that this research should be prioritized? Are there certain facilities you would upgrade first? How would you prioritize the upgrades?

Response 1: The facilities to upgrade, their degree of upgrade and the priority to undertake this effort must be part of a comprehensive national plan as articulated in recommendation No. 1 of the report "Assessment of Earthquake Engineering Research and Testing Capabilities in the United States," prepared by EERI, September 1995. Such a plan must: 1) Address effective use of existing facilities and personnel, upgrade obsolete and deteriorated equipment and support facilities, and incorporate emerging, innovative testing strategies; 2) Embody a comprehensive national research program that capitalizes on the renewed experimental capabilities in such a way as to meet the needs to reduce earthquake losses with a sense of national urgency; and 3) Build upon the collective input of all stakeholders, including design professionals, earth scientists, emergency managers, academics, building officials, insurers, financial representatives, code officials and community leaders. This stakeholder group should have a strong influence on priority setting for a national program.

Q2: Enclosed please fined a statement from Dr. Barton Krawetz, Vice President and General Manager of the Applied Engineering and Development Laboratory at Idaho National Engineering Laboratory. I ask that you review the statement and comment on it.

Response 2: While it may be tempting to Congress to make its job very easy by handing the whole NEHRP program to INEL and let them take care of everything using a "total systems approach," I find the INEL proposal seriously flawed in several respects.

Everyone seems to agree that wide scale implementation is the needed next step. I disagree, however, that INEL, or any other national laboratory for that matter, is the model of successful technology transfer to make that happen at the pace required. History has shown us that the "technology push" approach proposed simply doesn't work in this market. Most of what I have heard and read (except from the true technology wonks) matches my own experience as a practitioner and technology user. It points to a necessity to give top priority to the incentive side of the equation -- to create demand pull.

The INEL strategy hinges upon engaging the user community financially in order to unsure implementation of solutions. It sounds appealing, and I wish it could be true, but the construction industry traditionally under invests in R&D and technology innovation. It seems highly unlikely to expect sudden increases in private sector financial support of a NEHRP-type program. Any increased industry support in the future, unfortunately, will serve to only partially offset possible reductions in federal funding of R&D programs across the board. The trend of doing more with less is going to be with us for some time.

Full-scale testing is a necessary link in the research chain and is the key component of the INEL proposal. It, like the budget discussions going on now between the Congress and the Administration, must be viewed within the context of the whole, not examined and approved or discarded one program at a time. As stated in the report, "Assessment of Earthquake Engineering Research and Testing Capabilities in the United States," by EERI, September 1995, the highest priority needs to be given not to establishing a centralized full-scale test facility, but to: 1) Upgrading what we have, 2) Using these upgraded facilities to their capacity, and 3) Developing a comprehensive plan to integrate existing laboratories and personnel across the U.S.

I fully support the recommendations of the EERI assessment report. These recommendations have the collective support of the nation's leading experts in earthquake engineering research, and this approach allows for consideration of fresh initiatives, such as INEL's, into an integrated, strategic national plan that optimizes the use of all resources.

Q3: Should FEMA be mandated to establish specific and measurable goals for NEHRP? What should these goals be? Is this issue adequately addressed in the report "Strategy for National Earthquake Loss Reduction?"

Response 3: FEMA, as lead NEHRP agency, should not unilaterally establish the goals. Rather FEMA should serve to facilitate the process of establishing such goals by the stakeholder communities. Yes, the goals must be specific and measurable, and progress must be monitored regularly, with provisions for corrective action to be taken when appropriate. Oversight of this process at the highest level is necessary for success

The goals themselves are adequately addressed in the OSTP report, "Strategy for National Earthquake Loss Reduction," October 1995. However, as stated in that report, the strategy calls for a national prioritized research and mitigation agenda to be confirmed or adjusted on a regular basis to incorporate changing national needs and unique requirements.

Q4: Should an agency other than FEMA or the three NEHRP agencies manage the program? If yes, explain how you would restructure the program?

Response 4: I do not believe that it is our place to express a preference on overall program management leadership agency. However, FEMA comes closest to having it now.

I fully support leadership, coordination and restructuring of a revitalized national program led by an integrated program office within FEMA as described in the OSTP report, "Strategy for National Earthquake Loss Reduction," October 1995.

Federal Emergency Management Agency
Washington, D.C. 20472

November 29, 1995

The Honorable Steven H. Schiff
Chairman, Subcommittee on Basic Research
Committee on Science
United States House of Representatives
Washington, D.C. 20515

Dear Mr. Chairman:

As requested in your letter of November 10, I am transmitting hereby responses to questions for the record of hearings on the National Earthquake Hazards Reduction Program. Thank you for the opportunity to testify and for your support of earthquake hazards reduction.

Sincerely,

Richard T. Moore
Associate Director for Mitigation

Q. How will the goals outlined in the "Strategy for Earthquake Loss Reduction" be measured?

A. In the body of the report, each of the goals has a number of targets associated with it. Some of these targets have a specific time associated with their completion. Further, in Appendix C of the document, many of the targets list specific products that are expected to be produced as these targets are met. The degree to which the targets are met or the products are produced are measurable indications of the progress being made. Overall coordination of the National Earthquake Loss Reduction Program (NEP) will be assigned to a Program Officer in the Federal Emergency Management Agency. The activities and progress of the Program will be overseen by the Subcommittee on Natural Disaster Reduction of the Committee on Environment and Natural Resources, a Committee within the National Science and Technology Council. Additionally, FEMA, as the lead Agency for the Program will continue to report to Congress every two years.

Q. What is FEMA doing specifically to reduce non-structural damage or "contents damage" losses? Should NEHRP resources be shifted toward research in this area or toward implementation practices that are known to reduce this particular type of damage?

A. There are several activities currently underway that address non-structural damage issues. First, the results of both laboratory research and in-field investigation of non-structural earthquake effects are incorporated in the periodic updates of the "NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings," the resource document that forms the basis for the seismic provisions of the nation's three model building codes. Both the "Provisions" and the model codes include increased design requirements for critical facilities (such as hospitals and shelters) that would reduce non-structural damage. The model codes address this issue for critical facilities only, since the codes generally address life safety issues. However, the guidance is available for any designer or owner who wishes to minimize this type of damage to their buildings.

Further, within the ongoing project to develop Rehabilitation Guidelines for Existing Buildings we are including guidance relating to the performance of non-structural elements. This guidance will be presented in a way that will permit the building owner, architect and engineer to establish clear goals for seismic performance and to design with a reasonable degree of confidence that these performance objectives will be met.

FEMA is also beginning to fund the development of performance-based design criteria that could be used during the design and construction of a building to improve its expected level of performance. Higher performance levels would include reduction of non-structural damage. The criteria will build on the performance goals established in the Existing Buildings project and several related efforts. This process is a complex one that will take several years.

Finally, based on documented examples from the Northridge earthquake, FEMA has revised its publication entitled "Reducing the Risks on Nonstructural Earthquake Damage," and is revising "A Home Builder's Guide to Seismic Resistant Construction" to include material on reducing non-structural damage.

In summary, FEMA is taking action to address the issue of non-structural damage resulting from earthquakes. However, until there is wider implementation of the measures that can be taken now, FEMA does not believe we should devote additional scarce NEHRP resources to this area.

Q. Should the NEHRP program include cost-benefit analyses of building codes?

A. In my opening statement I mentioned a contract between FEMA and the National Institute of Building Sciences to develop a nationally-applicable standardized methodology for estimating earthquake losses on a regional basis. We intend to offer this methodology to States to serve as a basis for their risk analyses. These analyses will be the foundation upon which a whole series of decisions can be made. By providing a quantified and graphic description of the impact of a credible potential earthquake, this tool can serve as a point of departure for the policymakers and the general public in discussions on how - or whether - resources should be applied to address the vulnerability, and to what degree. Further, as I mentioned in response to your earlier question, material is being developed to assist in cost-benefit decisions involving the rehabilitation of existing construction. FEMA has developed a model, with associated software, that allows users to conduct a benefit/cost analysis of a seismic rehabilitation design of a single building or of an inventory of buildings. The model has been used as a general guide in both pre-and post-earthquake decisionmaking.

Further, we have done sufficient work to estimate that the cost of applying the "NEHRP Recommended Provisions" to new construction is generally less than 2% of the building cost, exclusive of land and furnishings.

As you can appreciate, these cost-benefit determinations are very site and scenario dependent; the efforts underway to provide more detailed and useful earthquake hazards maps, combined with the activities I have just mentioned, should significantly improve the ability of policymakers to assess the cost-benefit impact of building codes.

Q. The report "Strategy for Earthquake Loss Reduction" would bring all federal agencies with earthquake-related activities into the National Earthquake Loss Reduction Program (NEP) to "avoid duplication and ensure focus on priority goals." However, we learned from the OTA report "Reducing Earthquake Losses" that NEHRP is unable to effectively coordinate among its four current agencies. How will this coordination problem be solved as new agencies are made a part of the program?

A. As a partial answer to your question, I would again refer to the "Strategy for Earthquake Loss Reduction" that lays out some fairly detailed goals and targets, to which the participating agencies have agreed. These will be of material aid to the Program Director in assessing priorities and measuring progress. As always, the issue of resources is the central one. We hope the strategy document will assist us in making the case for the resources to accomplish what we have agreed needs to be done. Also, the NEP calls for oversight by the Subcommittee for Natural Disaster Reduction - a component of the National Science and Technology Council. This should serve to provide additional focus to agencies' activities in earthquake hazard reduction. Finally, I referred in my statement to the development of a National Mitigation Strategy, designed to heighten national awareness of the need for and the benefits of taking action today to reduce loss and suffering tomorrow. We believe this increased awareness will benefit the NEP by providing greater urgency to its stated goals and targets.

Q. How does FEMA as lead NEHRP agency ensure that information reaches those who would be users?

A. There is no easy answer to that question, considering the breadth of the audiences for earthquake hazards reduction information. These audiences include, for example, the academic and research communities, architects, engineers, builders and building owners, code writing and enforcing officials, political leaders, insurance officials, and the general public. FEMA and the other NEHRP agencies try very hard to see that all of the relevant interests get the information they need in the form that they need it. The opening statements of the NEHRP agencies refer to support of technical information dissemination centers, multi-state consortia, and cooperative work among Federal agencies and with the private sector in constantly seeking ways to provide this information in a form that is more useful and responsive to their needs. Within the last year, FEMA received the results of a survey conducted for us under contract to get input from the user community on NEHRP products. The survey will be used to provide better customer service to those who make use of the results of our efforts.

United States Department of the Interior

U.S. GEOLOGICAL SURVEY
Office of the Director
Reston, Virginia 22092

In Reply Refer To:
Mail Stop 905

JAN 2 2 1996

Honorable Steve Schiff
Chairman, Subcommittee on Basic Research
Committee on Science
House of Representatives
Washington, D.C. 20515-6301

Dear Chairman Schiff:

This is in response to your letter of November 10, 1995, to Dr. Robert Hamilton forwarding questions from the Subcommittee on Basic Research in response to the National Earthquake Hazards Reduction Program hearing on October 24, 1995.

The responses to the Subcommittee's questions are enclosed.

If you need further assistance, please let us know.

Sincerely yours,

Gordon P. Eaton
Director

Enclosure

National Earthquake Hazards Reduction Program
October 24, 1995
Questions & Answers

Q. At USGS, what percentage of NEHRP research is performed externally?

A. In fiscal year 1995, enacted funding for the USGS NEHRP program was $48,915,000, of which $13,943,000, or 28.5%, was used for the external program. The external program includes $5M for Cooperative Agreements (Southern California Earthquake Center and seismic nets in California, the Pacific Northwest, Alaska, Utah, Nevada, the New Madrid seismic zone, southern Appalachians, and New England/New York) and $8M for grants.

Q. Is this an appropriate balance?

A. The external and internal programs are closely integrated and coordinated under a common program prospectus. The balance between them is considered to be appropriate.

Q. Does USGS use the global positioning system in its research?

A. Yes. At present, the USGS conducts extensive Global Positioning System (GPS) surveys of active seismic areas, including northern and southern California and the Pacific Northwest. The USGS is working with collaborators to expand our GPS coverage. In southern California, we are cooperating with NASA to greatly expand our coverage of continuously recording GPS stations in the greater Los Angeles area. In northern California, we are designing a continuous-recording GPS network with the University of California at Berkeley. And in the Pacific Northwest, the USGS has joined a regional consortia of universities and the Geological Survey of Canada to jointly plan a 60-station, continuous-recording GPS network. In addition, to the continuous-recording GPS stations, the USGS uses a number of roving GPS stations. Much of the San Andreas fault system in California, the Cascadia subduction zone, and selected areas in the intermountain west (Reno, Salt Lake City, Yellowstone) are periodically resurveyed with GPS.

In addition, the USGS mapping program uses GPS to accurately establish the camera-exposure stations (the exact horizontal and vertical position of the camera in the airplane when each aerial photograph is taken) as part of the National Aerial Photography Program. This technique is also being used to acquire aerial photographs in Antarctica that are needed to plan the route for a tractor train to transport material to rebuild the field station at the South Pole.

Further, GPS is used to provide highly accurate elevation data for surface water flow modeling in the South Florida Ecosystem Restoration Initiative where extremely low relief requires elevation accuracies of at least 15 cm to be achieved over wide areas.

Also, it is used to prepare highly accurate digital elevation models of levees along the Mississippi and Missouri Rivers in areas that were flooded during 1993.

Q. Is there more that you could do with this particular tool?

A. Yes. We anticipate that use of GPS technology will steadily grow in assessment of earthquake hazards and for numerous other earth science applications. Eventually GPS networks will be as extensive as networks of seismograph stations.

Q. What, if any, are the obstacles to using the global positioning system?

A. There are no technical obstacles; however, increased use is limited by funding.

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