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Expanding and Using Knowledge to Reduce Earthquake Losses:

The National Earthquake Hazards Reduction Program

Strategic Plan

2001 - 2005

The development and use of this strategic plan will result in a new era of coordination and advancement for the National Earthquake Hazards Reduction Program. It will serve as a mechanism to improve coordination among the agencies, and provide the broad vision that NEHRP will use to move forward boldly into the 21st century. This NEHRP Strategic Plan, respectfully submitted, represents the consensus view of the Policy Coordination Council (PCC).

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This Strategic Plan is submitted in response to PL 95-124 (as amended) and PL 101-614. It serves as an operational plan for the National Earthquake Hazards Reduction Program (NEHRP) agencies and guides Federal earthquake research, loss reduction, and mitigation efforts in the U.S. The plan articulates the mission and goals of the NEHRP, provides a framework for priority-setting and coordinating activities, and defines priority areas for the future.

The plan was developed jointly among the four NEHRP agencies, the Federal Emergency Management Agency (FEMA), the National Institute of Standards & Technology (NIST), the National Science Foundation (NSF), and the United States Geological Survey (USGS), and the earthquake stakeholder community. Two workshops, involving over 60 stakeholders, were held in 1999 and 2000 to help identify priority implementation activities (Appendices A and B). The input offered during the workshops has had a significant impact on the overall direction of future earthquake hazard mitigation efforts as identified in the Plan. The stakeholder involvement has assured that Federal efforts are coordinated with state and local governments as well as the private sector.

The plan is also responsive to the desire of Congress that NEHRP emphasize coordination of research activities, speedy transfer of new knowledge, and implementation of the results and technologies by the user community. This plan addresses demands for greater productivity, efficiency, and accountability from the Federal government.

The Government Performance and Results Act of 1993 requires agencies consult with Congress and stakeholders to clearly define their missions, establish long-term strategic goals, and set annual objectives linked to the goals. This Plan is consistent with these requirements.

This is a living document. Factors affecting earthquake risk reduction may change and evolve differently than expected, and therefore goals and objectives, priorities, strategies, and planning contexts may change over the life of this plan. Consequently, the plan will be reviewed biennially by the participating agencies to assess the status of implementation and refine or revise approaches based on experience. The biennial review will coincide with the requirement for a NEHRP report to Congress. A more formal and comprehensive review, to be performed every five years, will involve internal and external stakeholders and may result in more substantive changes.

The NEHRP Agencies

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List Of Acronyms And Abbreviations

Acronym	**Definition**
ANSS	Advanced National Seismic System
ASCE	American Society of Civil Engineers
ATC	Applied Technology Council
BSSC	Building Seismic Safety Council
COSMOS	Consortium of Organizations for Strong Motion Observation Systems
CREW	Cascadia Region Earthquake Workgroup
CUREE	Consortium of Universities for Research in Earthquake Engineering
CUSEC	Central U.S. Earthquake Consortium
EERC	Earthquake Engineering Research Centers
EERI	Earthquake Engineering Research Institute
EMPG	Emergency Management Performance Grant
EQNET	Earthquake Information Network
FEMA	Federal Emergency Management Agency
GPS	Global Positioning System
HAZUS	Hazards U.S.
IBC	International Building Code
ICC	Interagency Coordination Council
ICSSC	Interagency Committee on Seismic Safety in Construction
InSAR	Interferometric Synthetic Aperture Radar
IRC	International Residential Code
IRIS	Incorporated Research Institutions for Seismology
MAE	Mid-America Earthquake Center
MCEER	Multidisciplinary Center for Earthquake Engineering Research
NASA	National Aeronautics and Space Administration
NEES	Network for Earthquake Engineering Simulation
NEHRP	National Earthquake Hazards Reduction Program
NEIC	National Earthquake Information Center
NESEC	Northeast States Emergency Consortium
NETAP	National Earthquake Technical Assistance Program
NFPA	National Fire Protection Association
NISEE	National Information Service for Earthquake Engineering
NIST	National Institute of Standards and Technology
NSF	National Science Foundation
NSMP	National Strong Motion Program
PCC	Policy Coordination Council
PEER	Pacific Earthquake Engineering Research Center
SAFOD	San Andreas Fault Observatory at Depth
SCEC	Southern California Earthquake Center
USGS	U.S. Geological Survey
WSSPC	Western States Seismic Policy Council

Executive Summary

Earthquakes represent an enormous threat to the Nation. Although damaging earthquakes occur infrequently, their consequences can be staggering. As recent earthquakes around the world have demonstrated, high population densities and development pressures, particularly in urban areas, are increasingly vulnerable. Unacceptably high loss of life and enormous economic consequences are associated with recent global earthquakes, and it is only a matter of time before the United States faces a similar experience.

Earthquakes cannot be prevented, but their impacts can be managed to a large degree so that loss to life and property can be reduced. To this end, the National Earthquake Hazards Reduction Program (NEHRP) seeks to mitigate earthquake losses in the U.S. through both basic and directed research and implementation activities in the fields of earthquake science and engineering. This program is authorized and funded by Congress and is managed as a collaborative effort among the Federal Emergency Management Agency (FEMA), the National Institute of Standards and Technology (NIST), the National Science Foundation (NSF), and the United States Geological Survey (USGS). These four Federal organizations work in close coordination to improve the Nation's understanding of earthquake hazards and to mitigate their effects. The missions of the four agencies are complementary: FEMA, a component of the Department of Homeland Security, works with states, local governments, and the public to develop tools and improve policies and practices that reduce earthquake losses; NIST enables technology innovation in earthquake engineering by working with industry to remove technical barriers, evaluate advanced technologies, and develop the measurement and prediction tools underpinning performance standards for buildings and lifelines; NSF strives to advance fundamental knowledge in earthquake engineering, earth science processes, and societal preparedness and response to earthquakes; and USGS monitors earthquakes, assesses seismic hazard for the Nation, and researches the basic earth science processes controlling earthquake occurrence and effects.

Mindful of the increasing threat posed by earthquakes, NEHRP initiated a review of the scientific goals and strategies of the Program and a discussion of the opportunities and priorities for the five-year interval 2001-2005. This review and discussion culminated in the new strategic plan presented here. Shaping the plan are four goals that represent the continuum of activities in the Program, ranging from research and development to application and implementation. These four goals are as follows:

A. Develop effective practices and policies for earthquake loss-reduction and accelerate their implementation.

B. Improve techniques to reduce seismic vulnerability of facilities and systems.

C. Improve seismic hazard identification and risk assessment methods and their use.

D. Improve the understanding of earthquakes and their effects.

For each of these goals and their underlying objectives, specific implementation activities are identified. Taken together, these activities do not represent a dramatic redirection of the program, but instead serve to emphasize the importance of continued investment in several well-established focus areas complemented by directed growth into a few new strategic areas of opportunity. The latter represent areas where compelling, fundamental issues in earthquake hazard reduction overlap with emerging technological opportunities, resulting in unprecedented potential to make rapid advances in our knowledge and our implementation of such knowledge, leading to the reduction of vulnerability. Six especially promising opportunities stand out:

- Upgrading seismic networks to allow for real-time notification of earthquake activity and intensity of ground shaking,

- On-scale recording of strong motion to facilitate prediction of ground motion and its effects,

- Simulation and testing of earthquake engineering design parameters,

- Development of performance-based seismic design methods,

- Monitoring of active fault zones to constrain the conditions that prevail prior to, during, and after an earthquake, and

- Improving the effectiveness of earthquake risk mitigation efforts through utilization of both existing and new research in the social, behavioral, and economic sciences

In addition to these challenges, NEHRP must also invest in the development of enhanced loss-reduction policies and practices; increased use of research findings by the building science, earth science, and social science communities; improved technology transfer; expanded education on earthquake issues; and increased incentives for earthquake mitigation. These product-oriented activities are essential if the research and development efforts of NEHRP are to be translated in to real progress in earthquake loss reduction.

Management of this Plan is shared by the NEHRP agencies. Each agency brings its strengths and organization to bear in support of the NEHRP mission, and is committed to developing the coordinated and cooperative actions identified in this strategic plan. Joint action of the agencies and interagency coordination at all levels will be important including:

- Post-earthquake coordination

- Information dissemination

- Interagency Internet resources

- Coordinated project activities across agencies

- Coordination with external stakeholders

- Coordination of transfer of research into practice and technology

Strategic planning is a continuous process that flows from conception to planning, implementation, assessment, improvement, and reporting. A biennial review will be carried out by the participating agencies to assess the status of implementation and to refine NEHRP's focus based on experience. In addition, a comprehensive review of the NEHRP Strategic Plan will be performed every five years, which may result in substantive changes in NEHRP's activities.

Introduction

Earthquakes represent the largest single potential source for casualties and damage from a natural hazard facing this country. Although the location varies, the pattern is the same: an earthquake strikes without warning, leaving cities in rubble and killing tens to hundreds of thousands of people. Worldwide during the 20th century, there were ten earthquakes that each killed in excess of 50,000 people, and over 100 earthquakes that killed in excess of 1000 people.

The U.S. has been fortunate in recent years in that its urban centers have largely avoided a direct hit from a "major" (M7.0 or greater) earthquake. Since the great Alaska earthquake of 1964, there have been twenty-six major earthquakes in the U.S. and none has claimed more than 65 lives. One reason for this low impact is that most of these events occurred in remote areas such as the Aleutian Islands or the Mojave Desert. Even the two most noteworthy events—the M7.1 Loma Prieta earthquake of 1989 and the M6.7 Northridge earthquake of 1994 (both with significant damage costs—occurred along the fringes of major metropolitan areas and struck during off-hours when impact was reduced.

It is only a matter of time before one or more large earthquakes strike the U.S. in a densely populated region. All but seven states in the U.S. are exposed to significant earthquake risk, including many large metropolitan areas. FEMA, a component of the Department of Homeland Security, estimates that the current annualized earthquake loss for the U.S. is $4.4 billion per year (*HAZUS 99 Estimated Annualized Earthquake Losses for the United States,* FEMA #366, Sept. 2000). This estimate, however, represents the expected loss averaged over many years. If a large-magnitude earthquake strikes a major metropolitan area, the actual loss will be significantly larger.

One only needs to look to Japan's experience during the 1995 Kobe earthquake to appreciate the catastrophic potential of even a moderate urban earthquake. The M6.7 Kobe earthquake—similar in size and duration to the Northridge earthquake—caused $100-200B in damage and approximately 5500 fatalities. The earthquake's impact was significantly larger than that of the Northridge earthquake ($40B and 57 lives lost), which ranks as the costliest natural disaster to strike in the U.S. The high price tag of the Kobe earthquake is due principally to its location—the event was centered beneath a highly urbanized region whereas Northridge was positioned beneath the northern edge of the Los Angeles metropolitan area. The U.S. was lucky.

Vulnerability to earthquakes in the U.S. is growing at an alarming rate. Population growth, urbanization, and infrastructure expansion are all contributing to this trend. In addition, a large inventory of existing structures lack earthquake-resistant design and have not been retrofitted to meet current design codes. A large-magnitude earthquake near one of several urban regions could cause thousands of deaths and financial losses approaching $100-200 billion. Bold action must be taken today to counter this trend and to develop effective, long-term, sustainable strategies for building earthquake-safe communities. An action plan to achieve this goal is the focus of this document.

Background

Responsibility for reducing earthquake risks is shared by Federal, state, and local governments and the private sector. The National Earthquake Hazards Reduction Program (NEHRP) is the Federal government's coordinated approach to addressing earthquake risks. NEHRP was established by Congress in 1977 as a long-term, nation-wide program to reduce the risks to life and property in the U.S. resulting from earthquakes. NEHRP comprises the Federal Emergency Management Agency (FEMA), the National Institute of Standards and Technology (NIST), the National Science Foundation (NSF), and the United States Geological Survey (USGS). The premise of the Program is that while earthquakes may be inevitable, earthquake disasters are not.

The NEHRP agencies work jointly and in cooperation with other Federal and state agencies; local governments; private companies; academic institutions; and regional, voluntary, and professional organizations to improve the Nation's understanding of earthquake hazards and to develop methods to reduce their effects. Underpinning earthquake risk reduction is research that develops new knowledge about, and understanding of, 1) the earthquake hazard, 2) the response of the natural and built environment to that hazard, and 3) techniques to mitigate the hazard. The foremost challenge facing NEHRP is encouraging the use of knowledge to foster risk reduction among local and state agencies and private entities.

Statement of the program's mission provides strategic guidance:

> *The mission of the National Earthquake Hazards Reduction Program is to develop and promote knowledge and mitigation practices and policies that reduce fatalities, injuries, and economic and other expected losses from earthquakes.*

The four NEHRP agencies each contribute their own unique set of skills and capabilities to the combined NEHRP mission:

FEMA has primary responsibility for overall planning and coordination of the NEHRP program. FEMA works to translate the results of research and technology development into effective earthquake loss reduction measures at state and local levels of government. It supports public-private partnerships to develop disaster-resistant communities, helps state and local government decision-makers by providing estimates of potential losses due to earthquake hazards, develops earthquake risk-reduction tools and measures, prepares technical guidance aimed at improving the seismic safety of new and existing buildings and lifelines, and prepares and disseminates information about building codes and practices. FEMA also develops and supports public education to increase awareness of earthquake loss reduction measures.

NIST is responsible for problem-focused research and development in earthquake engineering aimed at improving building codes and standards for both new and existing construction and advancing seismic practices for structures and lifelines. This work is focused on removing technical barriers, evaluating advanced technologies, and developing measurement and prediction tools underpinning performance standards needed by the U.S. design and construction industry.

NSF supports a broad range of basic research covering the geoscience, engineering, economic, and social aspects and impacts of earthquakes. NSF supports basic research into the causes and dynamics of earthquakes, plate tectonics, and crustal deformation. It funds research on geotechnical, structural, architectural, and lifeline systems and expands the Nation's earthquake engineering research capabilities. NSF supports research on the social, behavioral, and economic aspects of earthquake hazard mitigation. It also supports the education of new scientists and engineers, the integration of research and education, and outreach to professionals and the general public.

The USGS conducts and supports basic and applied earth science investigations that increase knowledge about the origins and effects of earthquakes, produces national and regional assessments of seismic hazards, and carries out engineering seismology studies of ground shaking. USGS also has primary responsibility for monitoring earthquake activity in the U.S. and for coordinating post-earthquake reconnaissance investigations. USGS supports an external research program and works with a number of partners and stakeholders to transfer its earthquake-related products into practice.

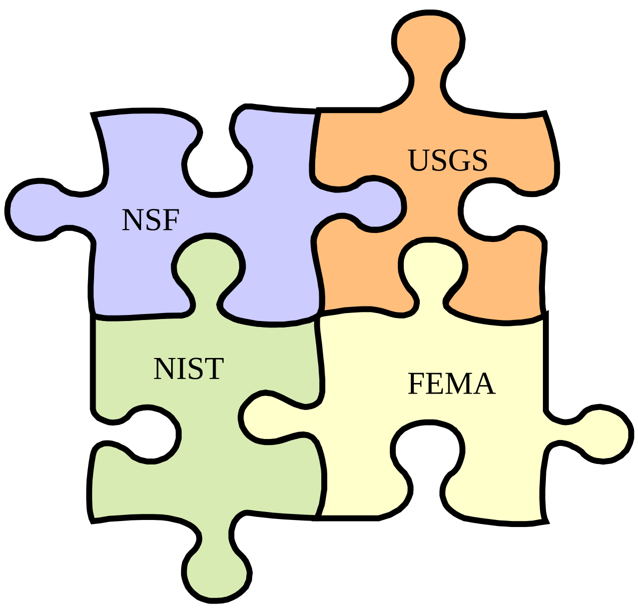

Figure 1. Interconnection of the four NEHRP agencies

The activities of the NEHRP agencies form a complementary program that has the ultimate aim of reducing earthquake losses across the Nation. At its foundation is research, which underpins nearly all of NEHRP's activities. The basic research supported and conducted by NSF and USGS extends across a number of earthquake-related disciplines including earthquake engineering, seismology, geology, and the social sciences. The knowledge gained from this basic research is utilized by NIST to help industry adopt and use innovative technologies through problem-focused research and development aimed at removing technical barriers, evaluating advanced technologies, and developing measurement and prediction tools underpinning performance standards for buildings and lifelines.

Similarly, an improved understanding of earthquake processes is utilized by the USGS to develop long-range earthquake probability forecasts, hazard assessments, and ground motion maps. FEMA then synthesizes the NIST and USGS applied research results into useable loss-reduction tools and methods. It also uses the research results to guide policy and practice in seismic risk reduction. Feedback loops at every step in the process stitch these separate program pieces—and the stakeholder community—together, so that results are shared, product needs are communicated back to the researchers, and program priorities are revised as needed.

An example of how this coordinated process has been effective in the past is presented here as insight into the way in which NEHRP expects to operate in the future. This example describes the research-to-practice pipeline that has been the lifeblood of NEHRP.

Example of NEHRP Coordination: State-of-the-Art Building Codes
An excellent example of the success of the NEHRP process is the incorporation of seismic provisions into the International Building Code (IBC), International Residential Code (IRC), and the codes being developed by the National Fire Protection Association (NFPA). Building codes have been recognized as one of the most effective tools for mitigating earthquake losses, and NEHRP activities have had a direct effect on the building code process in the United States, even though NEHRP has no regulatory authority. This process shows the success of both long term and short-term efforts on the part of NEHRP.

Over the past 20 years, a significant body of basic research work has been accomplished by NSF and the USGS in the areas of earthquake engineering, geoscience, and seismology. This fundamental research work, and the use of the earthquake monitoring networks by USGS, has allowed the development of detailed seismic hazard maps by USGS, and the development of significant earthquake engineering knowledge by NSF.

In parallel, FEMA, with the assistance of NIST, has developed and continued to refine the *NEHRP Recommended Provisions*, a guidance document for the seismic design of structures; directly incorporating the results of scientific advances of both NSF and USGS. The seismic hazard maps developed by USGS are directly referenced in the *Provisions*, and NSF research results are used throughout the document. In addition, during the periodic revisions of the *Provisions*, numerous unresolved issues have been forwarded back to USGS and NSF for their attention in future research. This guidance document within the engineering profession is regarded as the state-of-the-art in earthquake design guidance.

National implementation of new design standards is done through the adoption and enforcement of building codes. FEMA and USGS work with state and local governments and multi-state consortia to improve hazard identification and to promote the adoption of the building codes in seismically at-risk communities and states. In addition, the *NEHRP Recommended Provisions* was selected by model code organizations to be the basis for the seismic design provisions of the IBC and IRC, and will also be the basis of the codes being developed by NFPA.

This example clearly shows the significant and direct impact that NEHRP activities and coordination have had on the seismic safety of citizens, and the critical need to continue to invest in, and strengthen, the NEHRP partnership.

Future Challenges, Opportunities, and Priorities

As we begin the twenty-first century, the estimated impact of a major urban earthquake is increasing dramatically as urban growth and capital investment in earthquake-prone areas continue.

In particular, NIST currently occupies a critical niche in the Program: mining the basic earthquake engineering research of NSF and developing applied products and engineering guidelines that can be implemented by FEMA to reduce earthquake risk. Historically, the relative breakdown in funding among the agencies has been as follows:

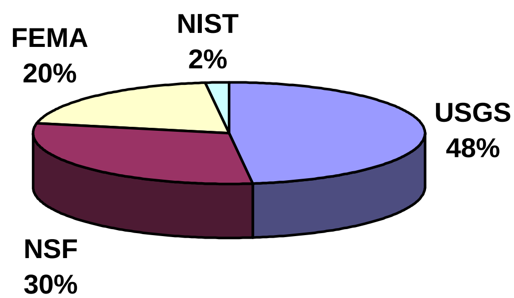

Figure 2. Relative Funding Levels of NEHRP Agencies

NEHRP has made substantial progress in hazards reduction since its inception in 1978. NEHRP has succeeded in establishing regional and national seismic networks that provide reliable, rapid information on recent earthquake activity for decision makers and the public. NEHRP has integrated 20 years of seismological, geophysical, and geological research into national seismic hazard maps that portray seismic hazards in a probabilistic sense and which quantify expected ground motions. These hazard assessments and their underlying databases are now being used in conjunction with NEHRP-developed loss-estimation tools to assess earthquake risk and to design strategies to mitigate it. From an engineering perspective, NEHRP has succeeded in providing improved design guidance for new and existing buildings, and in working with local governments, advocacy groups, and professional engineering associations to see that these guidelines are adopted and incorporated into building codes. NEHRP researchers continue to advance earthquake-engineering technology while working closely with industry to translate this new technology into practice. NEHRP has also excelled at translating the technical research results from the earth and engineering sciences into tools, guidelines, and informational products that are distributed to state and local governments, emergency managers, professional societies and other stakeholders to elevate the state of knowledge on earthquake issues across the country. The overall success of NEHRP is reflected in the resilience of communities that have been tested by significant earthquakes during the past decade. But these same communities also demonstrate that there is still progress to be made.

Looking forward, a number of compelling issues confront NEHRP. These issues occur on multiple time lines: some are more immediately addressable (10-15 years), while others may not deliver a payoff for many years. The most noteworthy challenges are as follows:

- Providing real-time reports of seismic activity and associated shaking intensity,
- Predicting ground motions in at-risk urban areas and determining how these ground motions interact with structures,
- Understanding performance of structural systems,
- Designing structures to explicitly reduce financial losses,
- Predicting earthquakes and their magnitude, and
- Improving the effectiveness of earthquake risk mitigation efforts through utilization of both existing and new research in the social, behavioral, and economic sciences.

In this report we propose several new or expanded research and development activities specifically designed to address these future challenges. Each of these proposed activities is a high priority for NEHRP and each is designed to complement ongoing NEHRP activities. Because of the scope and magnitude of these proposed activities, however, the ability of the NEHRP agencies to implement them is limited under existing funding. We summarize these proposed activities as follows:

<u>Real-Time Seismic Monitoring and Reports of Ground Motion Intensities</u>
Recent and unprecedented advances in information technology, telecommunications, and digital electronics now allow for real-time, high fidelity monitoring of seismicity across the Nation. An upgraded seismic monitoring system in the U.S. would enable rapid assessments of the distribution and intensity of earthquake shaking, thereby allowing emergency response officials to assess, within minutes of an event, where damage is likely to be concentrated and how emergency resources should be allocated. Someday, the new technology may even allow for a few seconds of warning of impending strong seismic shaking from distal earthquakes already in progress. The USGS funds the Advanced National Seismic System (ANSS) an effort to update current instrumentation and provide this real-time monitoring capability.

<u>Prediction of Strong Ground Motion and Its Effect on Structures</u>
The first step to predicting ground motion is to expand the observational database of strong motion recordings. Few if any complete recordings of strong motion near an earthquake's source have ever been recorded. Typical seismic networks are composed of sensors designed to record earthquakes at great distances from an earthquake; these sensors go off scale when strong shaking occurs at distances near the instrument. With improved recordings and more detailed information on geologic structures and near-surface physical properties, it will soon be possible to compute synthetic time series that contain all of the critical information on the expected ground shaking, in addition to its duration. These synthetic time histories are needed by engineers if they are to determine how ground motion interacts with structures and consequently, how to improve engineering design standards. The ANSS, described above, calls for instrumentation that would permit on-scale recording of seismic shaking at over 7000 ground-based sites and structures. ANSS expands the observational database of ground motion recordings, thereby providing data that are critical to improving design standards and building practices.

Earthquake Engineering Simulation and Testing

Improved engineering design standards have traditionally followed from observational testing, where the observation was made from testing on-scale models and structural components in an experimental facility or observed during post-earthquake reconnaissance. However, dynamic testing of full-scale structures subjected to strong shaking is both logistically difficult and prohibitively costly. Fortunately, increased computational capabilities now allow for a new means of engineering design testing through computer simulation. The latter can be directed at both individual structural components and at integrated systems. Testing of complex structures and processes can be performed with real-time coordination at several facilities with enhanced capabilities and information stored and shared on-line, using Internet technology to integrate and interconnect nationally distributed facilities. The resulting information would then be integrated into improved guidelines for practice and activities that include NIST and FEMA. The NSF has secured funding to develop such a facility, referred to as the Network for Earthquake Engineering Simulation (NEES), which is expected to be on-line in 2004. The facility will include linkages to observational data acquired by USGS through ANSS, thereby allowing calibration of simulation results with observed strong motion recordings from structures and lifelines.

Performance-Based Seismic Design

Building codes have traditionally been designed to limit loss of life, not to guarantee a specific level of structural performance. In principle, however, it is possible to design for a range of performance objectives (i.e., “damage states”) for a given seismic event. This concept, known as performance-based design, represents the next generation of code development and is a high priority for NEHRP. In addition to the need for performance-based designs for buildings, there also is a need to develop performance-based standards for lifelines. Lifelines include transportation systems (bridges, highways, railroads, airports), water and sewerage, electric power, communication systems, and gas and liquid fuel pipelines. With the exception of bridges and large buildings, most lifelines are constructed without any special codes or guidelines for seismic resistance. The production of performance-based design codes for buildings and lifelines would allow the owner and builder to design a structure to an acceptable damage state, i.e., they could explicitly design for reduced financial losses. The end result would be a better understanding of the economic implications of the seismic risk and the ability to manage that risk. A NEHRP effort to develop performance-based codes is proposed herein and would be lead by FEMA and NIST, with support from NSF and USGS.

Monitoring of Strain and Physical Properties Within and Across Active Fault Zones

The ultimate goal for earthquake seismologists is the prediction of earthquakes. Currently it is not clear that earthquake prediction is realizable; earthquake nucleation may be an inherently unstable process that does not lend itself to prediction. However, it is possible to monitor active fault zones to diagnose their strain state and to capture the conditions that prevail when an earthquake initiates. New technologies utilizing advanced drilling techniques and satellite-based geographic positioning systems (GPS) now afford unprecedented opportunities to measure strain accumulation and the physical conditions under which earthquakes occur.

As part of a new initiative known as EarthScope, NSF is proposing to develop four new earth science facilities that will contribute to NEHRP goals: USArray, the San Andreas Fault Observatory at Depth (SAFOD), the Plate Boundary Observatory (PBO) and the Interferometric Synthetic Aperture Radar (InSAR) satellite. Multi-agency partnerships will be necessary to accomplish the construction of EarthScope including USGS and NASA. USArray will determine the detailed 3-dimensional structure of the earth's crust, which will be necessary to develop estimates of earthquake ground motion. SAFOD is designed to monitor physical properties *within* the earthquake zone of the San Andreas Fault. This observatory will revolutionize the understanding of earthquake processes by enabling, for the first time, direct measurement of the physical conditions under which earthquakes occur and will allow for direct observation of the processes of earthquake ruptures. Both PBO and InSAR permit measurement of the rate and distribution of strain buildup and release before, during, and after earthquakes. PBO will consist of high precision, continuously recording GPS receivers and strain meters that will permit measurement of the rate and distribution of strain buildup. InSAR also measures crustal distortion but with revolutionary spatial resolution. All elements of EarthScope are designed to complement each other to provide an integrated picture of the structure and dynamics of the earth's crust. Collectively these facilities are essential if NEHRP is to advance the physical understanding of the mechanics of earthquakes and determine whether earthquake prediction will ever be possible.

Improved Use of Social Sciences to More Effectively Mitigate Earthquake Risks

One of the historic problems in successful implementation of earthquake risk reduction efforts has been the lack of understanding of factors that motivate action. A considerable body of knowledge in the areas of social, behavioral, and economic science exists that can provide great insight into the nature of decision making, risk communication, and the human dynamics involved in hazard mitigation. In addition, there is a need for both continued focused research and transfer of research results into practice in this area. FEMA and NSF will work together to identify and transform existing research into practice, and to identify topics where further research is needed.

Each of the topics discussed above represent scientific and technologic growth areas that have the potential to deliver dramatic advances in our understanding of earthquake processes and our ability to mitigate their effects. As such, these new growth areas symbolize new lifeblood for NEHRP's research-to-application pipeline, which is the foundation of the Program's success. Support for research in science and technology alone, however, is not sufficient. Success cannot be achieved without the effective and timely transfer of information to the myriad of potential users, ranging from the general public to engineers, planners, government officials, business leaders, and many others.

In the pages that follow, the NEHRP agencies outline a bold action plan for developing effective, long-term, sustainable strategies for building earthquake-safe communities. This plan provides the necessary balance among the research, development, and implementation activities of NEHRP and is structured around four main goals. These goals do not stand alone, but instead are strongly linked such that knowledge gained under one goal feeds research, development, and implementation efforts in the other goals. For this reason, overall success in earthquake mitigation requires that efforts in the four programmatic areas be appropriately coordinated.

Specific implementation activities are discussed separately for each of the four goals. In addition, a philosophy is also presented that will guide how the NEHRP agencies implement Program management and coordination, and how they will measure program performance.

Goals and Objectives

Goals

The goals and objectives of NEHRP lay a foundation on which the program builds its mission to reduce earthquake losses. The goals are of equal priority and are mutually dependent:

A. Develop effective practices and policies for earthquake loss-reduction and accelerate their implementation. *Promote earthquake loss-reduction activities and support those who adopt, implement, and enforce such policies and practices.*

B. Improve techniques to reduce seismic vulnerability of facilities and systems. *Develop, improve, and disseminate products that guide design and construction practices and land-use planning, and improve professional practice.*

C. Improve seismic hazards identification and risk-assessment methods, and their use. *Develop, improve, and disseminate products that portray earthquake-related hazards accurately and quantify seismic risk.*

D. Improve the understanding of earthquakes and their effects. *Support research to understand the processes that lead to earthquakes and associated hazards and to advance engineering, social, behavioral, and economic knowledge.*

Objectives

The following objectives indicate how the NEHRP agencies will achieve each goal:

Goal A. Develop effective practices and policies for earthquake loss-reduction and accelerate their implementation.

1. Develop and provide information on earthquake hazards and loss-reduction measures to decision-makers and the public. NEHRP will develop information to increase knowledge about earthquake hazards, to understand the risks, and to assist decision-makers in evaluating loss reduction alternatives. NEHRP will also foster development and dissemination of knowledge and tools that are formulated to meet user needs.

2. Promote incentives for public and private sector loss-reduction actions. NEHRP will support community-based efforts to develop and implement economic and other incentives that promote loss-reducing actions, and create disaster-resistant and sustainable communities.

3. Advocate state and local government practices and policies that reduce losses in the public and private sectors. NEHRP will collaborate with state and local government officials, associated advisory bodies, and regional earthquake consortia to provide technical and other assistance for developing, adopting, and evaluating earthquake loss-reduction measures in at-risk states and communities.

4. Implement policies and practices that reduce vulnerability of Federal facilities. NEHRP will support the Interagency Committee on Seismic Safety in Construction (ICSSC) and its member agencies in developing and implementing practices and policies for earthquake risk reduction for buildings and lifelines that are owned, leased, assisted, and regulated by the Federal government.

5. Develop the Nation's human resource base in the earthquake field. NEHRP will support education and training for engineers, practicing design and construction professionals, planners, facility managers, and emergency managers through continuing education programs. NEHRP will also support educational activities for university students, K-12 school children, and the general public to facilitate a broader, informed understanding of earthquake hazard, risk, and mitigation.

Goal B. Improve techniques to reduce seismic vulnerability of facilities and systems.

1. Facilitate technology transfer among standards organizations, state and local governments, and private-sector professionals. NEHRP will support development and publication of design, construction, evaluation, and upgrade guidelines and pre-standards for consideration by national organizations that develop codes and standards for buildings and lifelines. NEHRP will also develop tools to assist in the use of those guidelines. NEHRP will work with professional and trade associations to promote the use of new technology.

2. Improve earthquake loss-reduction knowledge and the quality of practice. NEHRP will support problem-focused and fundamental research by academia and the private sector to fill knowledge gaps and provide the technical basis for design, construction, evaluation, and upgrade guidelines and pre-standards. NEHRP will also support the exchange of information to maintain awareness of national and international developments in earthquake mitigation technology.

3. Support efforts to improve seismic standards and codes and improve design and construction practices for buildings and lifelines. NEHRP will support periodic revision of the *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures*, application of the *NEHRP Guidelines for the Seismic Rehabilitation of Buildings,* and development of design and construction criteria for lifelines, including utility and transportation systems. NEHRP also will support post-earthquake investigations to identify knowledge gaps and will conduct studies to address special problems identified after major earthquakes.

Goal C. Improve seismic hazards identification and risk assessment methods, and their use.

1. Provide rapid, reliable information about earthquakes and earthquake-induced damage. NEHRP will continue to support the operation of regional data centers, the National Earthquake Information Center (NEIC), the Global Seismic Network (GSN), the International Seismic Centre (ISC), and the IRIS Data Management Center (DMC). In addition, NEHRP will deliver rapid, accurate reports on the intensity and distribution of strong ground shaking in urban areas following damaging earthquakes. NEHRP will also propose to implement the ANSS.

2. Improve seismic hazard characterization and mapping. NEHRP will improve hazard assessment methods and produce updated national-scale ground-shaking maps and related products on a regular basis. NEHRP will also work with cooperators to develop a standard methodology for production of large-scale seismic hazard maps for urban regions.

3. Support development and use of risk and loss assessment tools. NEHRP will support improvement of loss estimation and risk assessment tools and the development of next generation databases. Testing and dissemination of the nationally applicable loss-estimation model will continue. States and communities will be encouraged to provide detailed data on local geology, building inventories, and utility and transportation systems to enable more accurate planning and establishing of priorities.

Goal D. Improve the understanding of earthquakes and their effects.

1. Improve monitoring of earthquakes and earthquake-generating processes. NEHRP will continue to develop improved seismic monitoring capabilities geared toward full-waveform recording, real-time reporting, and improved network integration. NEHRP also will continue to support and expand other monitoring systems and the use of satellite-based observational systems for monitoring the deformation of the earth's crust due to earthquakes and earthquake-generating processes.

2. Improve understanding of earthquake occurrence and potential. NEHRP will support research into the processes by which earthquakes occur, including studies of how large earthquakes initiate and grow, the role of fault zone geometry and mechanical properties, and the effect of changes in earth stresses.

3. Improve earthquake hazards assessments and develop earthquake-potential estimates as planning scenarios. NEHRP will support a broad-based research program on earthquakes and ground failure by improving quantification and understanding of the extent of hazards and by encouraging use of that knowledge for planning purposes.

4. Improve fundamental knowledge of earthquake effects. NEHRP will support research on the nature of strong ground shaking from earthquakes, how it is affected by seismological and geological factors, and how its characteristics are related to permanent ground deformation and damage. These efforts will include investigations of damage from domestic and foreign earthquakes and collaboration with non-U.S. research programs.

5. Advance earthquake engineering knowledge of the built environment. NEHRP will implement the Network for Earthquake Engineering Simulation (NEES) to improve the seismic design and performance of U.S. civil and mechanical infrastructure systems through collaborative and integrated experimentation, computation, theory, databases, and model-based simulation.

6. Advance understanding of the social and economic implications of earthquakes. NEHRP will support earthquake-related social science and policy research to advance understanding of the social and economic impacts of earthquakes, determine levels of risk deemed acceptable by various groups in society, and reduce the social, economic, and political barriers to effective earthquake risk reduction.

Implementation

The following sections describe, by goal and objective, specific NEHRP priorities and activities that the agencies intend to pursue in the near term. Because the amount of available resources has a distinct bearing on the scope and breadth of activities, the discussion has been framed to reflect what can be accomplished at current funding levels.

Goal A. Develop Effective Practices and Policies for Earthquake Loss-Reduction and Accelerate Their Implementation

Through Goal A, NEHRP seeks to reduce the seismic vulnerability of the built and social environments by disseminating earthquake hazard and risk information and advocating risk reduction techniques. Activities identified under Goal A are designed to accelerate earthquake loss reduction in the public and private sector by engaging and supporting partners at the local, state, and national levels. FEMA is the primary agency carrying out Goal A efforts, with NIST, NSF, and USGS playing important supporting roles.

NEHRP will continue to use existing resources to develop partnerships as described in the sections below to provide risk assessment and risk reduction tools to local business and government leaders, to provide training to design and construction professionals, and to advocate the adoption and enforcement of state-of-the-art codes and land-use practices for buildings and lifelines.
The following sections address current and future NEHRP activities under each of the five objectives of Goal A.

1. Develop and provide information on earthquake hazards and loss-reduction measures to decision makers and the public.

NEHRP will develop information to increase knowledge about earthquake hazards, to understand the risk, and to assist decision-makers in evaluating loss reduction alternatives. NEHRP will also foster development and dissemination of knowledge and tools that are formulated to meet user needs.

Under Objective 1, NEHRP's priorities are to:

- Promote the use of NEHRP resource materials to evaluate seismic risk and mitigation alternatives.

- Work with professional organizations, universities, and local and national partners to distribute NEHRP products and promote adoption of risk reduction measures.

NEHRP and its partners generate a large range of products that address earthquake hazards, document the associated seismic risk, and provide loss-reduction alternatives. These products are largely the outgrowth of activities in Goals B, C, and D of the program. Successful mitigation requires that these products be effectively understood, distributed, accepted, and used, and that a broad base of earthquake-aware individuals be developed and nurtured at all levels. To accomplish these goals, NEHRP pursues a variety of different means to distribute its tools and products so that they can be utilized effectively. Publications, press releases, web sites, and symposia are some of the traditional means of information dissemination. FEMA-supported multi-state consortia (CREW, CUSEC, NESEC, and WSSPC) are utilized as coordinators and policy centers for states and communities with similar seismic risk characteristics. Additionally, NEHRP works with its grantees in the regions, such as the three NSF-supported earthquake engineering research centers (MCEER, MAE, PEER) and the NSF/USGS supported multidisciplinary Southern California Earthquake Center (SCEC), to provide local outreach programs designed to educate the public, promote earthquake awareness, and develop strategies to transfer research findings into implementation.

NEHRP and its partners also work with professional organizations and multi-state consortia to develop the most effective means to communicate seismic hazard and risk issues and to better determine the needs of NEHRP audiences. This approach enables NEHRP to reach potential mitigation advocates effectively while also establishing a feedback loop to assure that projects are optimized to meet user needs. NEHRP provides the seismic expertise, while the professional organizations and regional consortia provide translation of the needs of their constituencies, such as the insurance industry, utility operators, facilities managers, design and construction professionals, and land-use planners. Funding for these collaborative efforts is often shared, thereby leveraging the ability of NEHRP to provide crucial knowledge transfer activities. In order to increase the promotion of risk reduction measures, NEHRP will increase its efforts to work with professional organizations to promote the use of risk-reduction tools by their members.

One professional group that receives special focus from NEHRP is the structural engineering community. NEHRP utilizes university-based earthquake engineering centers (MAE, MCEER, PEER) and related Internet distribution channels (e.g., EQNET, CUREE, and NISEE) as a means of disseminating earthquake information to the professional community and the general public. NEHRP also works directly with engineering-based professional organizations (EERI, BSSC, ASCE, ATC, COSMOS) to promote guidelines development, to coordinate post-earthquake activities, and to translate and disseminate research results to practicing engineers. In the future, the NSF-funded Network for Earthquake Engineering Simulation (NEES) project will be an increasingly important nexus for information flow from the experimental research community to practicing professionals, with translation of the research results to local decision makers and the public.

As the need for reducing risks becomes more urgent in increasingly developed, at-risk communities, NEHRP must reach beyond traditional end-users. State-of-the-art resources must be provided to a larger group of design professionals and those in the construction trades, as well as land-use planners, emergency managers, and public administrators. Products must be specially crafted to meet the needs and backgrounds of individual audiences. NEHRP will work with researchers in the behavioral, policy, and social sciences to determine the most effective means to communicate seismic hazard and risk-reduction messages to these target audiences. NEHRP will also expand its use of the Internet as a medium for product distribution and hazard awareness.

2. Promote incentives for public and private sector loss-reduction actions.

NEHRP will support community-based efforts to develop and implement economic and other incentives that promote loss-reducing actions, and create disaster-resistant and sustainable communities.

Under Objective 2, NEHRP's priority is to:

- Promote seismic risk reduction through partnerships with local communities and businesses. Advocate the use of incentives as a means of improving disaster resistance.

Mitigation is accomplished locally, and thus a successful earthquake mitigation program requires the involvement and commitment of local communities and businesses. Recognizing this, FEMA has established a nation-wide initiative to build disaster-resistant communities through local partnerships. This initiative is based on three principles: 1) preventive actions must be decided at the local level, 2) private sector participation is vital, and 3) long-term efforts and investments in prevention measures are essential. FEMA provides incentives for risk reduction activities within these communities, including small start-up funding as well as technical assistance through its National Earthquake Technical Assistance Program. FEMA, together with other NEHRP agencies, also works with communities to identify risks, prioritize needs, and develop long-term plans to protect each disaster-prone community. Increasingly, communities are using means such as the transfer of development rights into less hazard-prone areas to mitigate their risk. An essential element in the crafting of these mitigation strategies is the use of NEHRP tools and products (such as seismic hazard maps and HAZUS loss estimation software) to identify areas of a community that are most vulnerable to seismic hazards. FEMA also engages local and national businesses to promote disaster prevention efforts. One example is the promotion of low-interest loans—established in partnerships with banks doing business in the community—for mitigation of existing buildings. These activities are not only a good source of public relations for companies, they also result in more resilient communities, which improve the economic viability of the business over time. Finally, FEMA works with its NEHRP partners to promote the adoption of state-of-the-art building codes in communities and to insure access to, and use of, the latest seismic engineering design and retrofit techniques.

3. Advocate state and local government practices and policies that reduce losses in the public and private sectors.

NEHRP will collaborate with state and local government officials, associated advisory bodies, and regional earthquake consortia to provide technical and other assistance for developing, adopting, and evaluating earthquake loss-reduction measures in at-risk states and communities.

Under Objective 3, NEHRP's priorities are to:

- Promote seismic risk reduction at the state and local government level through partnerships with seismic advisory boards and multi-state earthquake consortia.

- Promote adoption of updated building codes by states and local governments to enhance seismic risk reduction.

- Encourage mitigation during disaster recover efforts.

The primary step that NEHRP advocates for at-risk states to achieve earthquake mitigation is to establish a seismic safety advisory board to serve as the statewide authority for seismic hazard identification and risk reduction. Currently 13 states and territories have established seismic safety advisory bodies. These boards provide advice to elected officials, develop seismic risk mitigation programs, and sponsor legislation directed at improving seismic safety. A goal of NEHRP is to expand this to all of the 45 states and territories that have been identified as having moderate to very high earthquake risk.

NEHRP also places a high priority on working with states and local governments to promote seismic risk reduction through the adoption of building codes with up-to-date seismic provisions. The first International Building Code (IBC) and International Residential Code (IRC), which include state-of-the-art seismic components, were released in 2000. NEHRP will increase its efforts to actively promote the adoption of this code by at-risk states and communities, as well as other seismic-resistant codes such as those recommended by the National Fire Protection Association (NFPA). (For a discussion of the NEHRP's building code role, see Goal B.) The enforcement of codes with seismic components that states and communities have adopted will be promoted through existing public and private-sector partnerships.

Through FEMA, NEHRP also provides financial and technical support on an annual basis to states and territories at moderate and high seismic risk as an incentive for these states and territories to work with their most vulnerable jurisdictions. Multi-state consortia (e.g., CREW, CUSEC, NESEC, and WSSPC) are also funded to serve as coordinators and policy centers for states with similar seismic risk characteristics. Lastly, FEMA uses the Emergency Management Performance Grant (EMPG) program to urge at-risk states to assess the vulnerability of their facilities, and to develop plans to reduce the identified risks.

A final area where NEHRP can work to reduce earthquake vulnerability is to encourage mitigation practices after natural disasters occur. After a disaster, affected citizens as well as local decision makers are frequently more receptive to mitigation, and this represents a tremendous opportunity to introduce earthquake mitigation measures. FEMA will therefore increase efforts to develop and provide earthquake mitigation tools and practices designed to be introduced into local disaster recovery efforts.

4. Implement policies and practices that reduce vulnerability of Federal facilities.

NEHRP will support the Interagency Committee on Seismic Safety in Construction (ICSSC) and its member agencies in developing and implementing practices and policies for earthquake risk reduction for buildings and lifelines that are owned, leased, assisted, and regulated by the Federal government.

Under Objective 4, NEHRP's priorities are to:

- Reduce the risk to existing and future Federal facilities through partnerships with Federal agencies.

- Provide state-of-the-art risk-reduction standards to all affected Federal agencies.

The Federal government must set an example for both the public and private sectors, including the implementation of effective hazard mitigation measures for more than 500,000 buildings that it owns, leases, assists, and/or regulates throughout the country. The ICSSC was established as part of NEHRP by the Earthquake Hazards Reduction Act of 1977 to assist Federal departments and agencies in developing and incorporating earthquake hazard reduction measures into each organization's ongoing facilities management program. The chair of the ICSSC is the Director of NIST or his designee, who reports to FEMA leadership. FEMA, NIST, NSF, and USGS are ICSSC member agencies. Twenty-eight other Federal departments and agencies are also members of the ICSSC, which recommends uniform practices and policies to reduce earthquake risk at both new and existing Federal facilities, including buildings and lifelines. These ICSSC recommendations are primarily embodied in two Executive Orders: *EO 12699, Seismic Safety of Federally Assisted or Regulated New Building Construction*, and *EO 12941, Seismic Safety of Existing Federally Owned or Leased Buildings.* FEMA has overall responsibility for carrying out Executive Orders, and provides progress reports to Congress; FEMA and NIST share responsibility in providing technical assistance to ICSSC member agencies in implementing the Executive Orders. To assure compliance with the requirements of the Executive Order, the ICSSC conducts periodic studies to compare the equivalence between the model building codes and standards issued by the private sector and the *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures*.

In the future, as NEHRP develops performance-based standards for buildings and lifelines under Goal B, the ICSSC will disseminate these next-generation materials to all Federal agencies and support implementation.

5. Develop the Nation's human resource base in the earthquake field.

> *NEHRP will support education and training for engineers, practicing design and construction professionals, planners, facility managers, and emergency managers through continuing education programs. NEHRP will also support educational activities for university students, K-12 school children, and the general public to facilitate a broader, informed understanding of earthquake hazard, risk, and mitigation.*

Under Objective 5, NEHRP's priorities are to:

- Develop and use partnerships to provide training in the use of NEHRP technical resource materials developed under Goals B, C, and D.

- Advocate the inclusion of seismic hazard and risk reduction information into curricula at K-12 schools and higher education institutions.

Because seismic risk-reduction activities are best carried out by local professional and construction trade organizations and by state personnel who are familiar with local issues and needs, NEHRP will increase its ongoing efforts to develop audience-specific risk-reduction tools, publications, and programs to meet the needs of these users. NEHRP will pursue this in cooperation with professional and trade membership organizations so that these organizations take a leadership role in training and educating their members. Similarly, as states and communities adopt seismic codes, NEHRP will work with code groups to support training and enforcement activities.

The education of the next generation of seismic risk reduction advocates and professionals is important to the continued success of NEHRP. This education must begin at an early age, so that a basic understanding of earthquakes and their consequences is broadly established. For this reason, FEMA, NSF, and USGS have participated in partnerships with other Federal agencies and non-governmental organizations to develop and advocate curricula for K-12 school children and university students on earthquakes and their effects. Universities also are supported by NSF to educate researchers and other earthquake professionals in all aspects of seismic issues (i.e., engineering, seismology, geology, social sciences, and public policy). These efforts will continue and will focus on promoting the use of these curricula and related educational activities in areas of very high to moderate seismic risk.

Goal B. Improve Techniques to Reduce Seismic Vulnerability of Facilities and Systems

The Goal B activities assure the availability of improved techniques to reduce the seismic vulnerability of facilities and systems. These improvements are achieved through several means, including: publication of design, construction, and evaluation guidelines for buildings and lifelines; development of tools to assist in the use of those guidelines; problem-focused research and development to fill knowledge gaps; execution of coordinated post-earthquake investigations; publication of associated longer-term studies to address special problems identified after major earthquakes; cooperation with professional and trade associations to improve the use of technology; advocacy to include research results in curricula and continuing education for practicing professionals; and international exchange of information on earthquake mitigation technology.

The following is a discussion of NEHRP activities supported under Goal B.

1. Facilitate technology transfer among standards organizations, state and local governments, and private-sector professionals.

> *NEHRP will support development and publication of design, construction, evaluation, and upgrade guidelines and pre-standards for consideration by national organizations that develop codes and standards for buildings and lifelines. NEHRP will also develop tools to assist in the use of those guidelines. NEHRP will work with professional and trade associations to promote the use of new technology.*

Under Objective 1, the NEHRP's priorities are to:

- Support strong model building codes; and

- Encourage technology transfer through professional organizations.

NEHRP supports the development and periodic revision of model building codes. The current trend is toward unified national codes for both new and existing buildings, such as those developed by the International Code Council and those being developed by the National Fire Protection Association (NFPA). These codes are replacing the three regionally based model codes and are expected to be implemented throughout the Nation. The *NEHRP Recommended Provisions* serve as the resource documents for these model building codes for new buildings, while the *NEHRP Guidelines for the Seismic Rehabilitation of Buildings* serve as the resource documents for code development for existing buildings. FEMA is the lead agency supporting the model building code efforts. The USGS' probabilistic seismic hazard maps define the level of seismic hazard as a function of geography, and are thus the basis for applying the seismic design criteria contained in the model codes. The USGS also produces interactive tools that enable determination of location-specific seismic design parameters that can be used with the model building codes and standards. The basic and applied research performed by NSF and NIST, respectively, directly supports the development of the technical provisions of NEHRP guidelines. In addition, the ICSSC conducts periodic studies to compare the equivalence between the model codes and the *NEHRP Recommended Provisions* and issues consensus recommendations based on its findings for adoption by Federal agencies. In the future, this level of effort will be sustained using existing program funds.

A second activity under Objective 1 is the dissemination of information and transfer of earthquake-resistant design and construction technology to users. These users include design and construction professionals, trade schools, and developers, among others. FEMA will be the lead agency in this effort, but will work in coordination with USGS and NSF efforts in science education. A baseline of activity directed at these audiences will proceed using existing funds.

2. Improve earthquake loss-reduction knowledge and the quality of practice.

> *NEHRP will support problem-focused and fundamental research by academia and the private sector to fill knowledge gaps and provide the technical basis for design, construction, evaluation, and upgrade guidelines and pre-standards. NEHRP will also support the exchange of information to maintain awareness of national and international developments in earthquake mitigation technology.*

Under Objective 2, NEHRP's priorities are to:

- Expand the use of problem-focused research and development to support codes and standards improvement.

- Carry out international exchange of information to keep abreast of state-of-the-art technology in earthquake mitigation.

NEHRP currently supports a modest program of problem-focused research and development to fill knowledge gaps and provide the technical basis for improved design, construction, evaluation and upgrade guidelines and pre-standards for buildings and lifelines. NIST is assigned lead responsibility for this activity, with supporting efforts from FEMA and NSF. NIST's research program, focused on the structural performance of buildings within a multi-hazard context, includes studies of: new performance-based seismic design approaches, evaluation of advanced structural control technologies, structural performance of housing systems, and strengthening and rehabilitation of structures. FEMA also contributes to studies of design and rehabilitation of welded steel-frame buildings and supports problem-focused research at university-based research centers and at the National Research Council.

This strategic plan includes a provision for increased emphasis of problem-focused research that will alleviate the "technology transfer gap" that is noted to exist for research outcomes. The current level of support in NEHRP for problem-focused research is insufficient to leverage the wealth of information emerging from basic research activities. As a result, a technology transfer gap has emerged which limits the adaptation of basic research knowledge into practice. This gap is expected to widen as NEHRP embarks on a new generation of performance-based provisions and guidelines for buildings and lifelines. A much-expanded problem-focused research and guideline development effort is critically needed for future design, construction, evaluation, and upgrade guidelines and pre-standards, and to facilitate the development of new mitigation technologies. NIST, in partnership with FEMA and the other NEHRP agencies, will develop a coordinated NEHRP plan to support an expanded level of problem-focused R&D. Recognizing that the U.S. is not the only developed country with an active earthquake engineering community, NEHRP must maintain awareness of international developments in earthquake mitigation technology and enhance learning through participation in international post-earthquake investigations and international information exchanges. Post-earthquake investigations in other countries provide rare opportunities to obtain important information on the performance and vulnerability of buildings and lifelines in major earthquakes. Similarly, formal and informal exchange mechanisms with the international community allow for enhanced sharing of research results and more rapid advancement of the science. These efforts, albeit modest, will continue as an integral part of NEHRP's strategy to reduce seismic vulnerability of facilities and lifelines.

3. Support efforts to improve seismic standards and codes and improve design and construction practices for buildings and lifelines.

> *NEHRP will support periodic revision of the* NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures, *application of the* NEHRP Guidelines for the Seismic Rehabilitation of Buildings, *and development of design and construction criteria for lifelines, including utility and transportation systems. NEHRP also will support post-earthquake investigations to identify knowledge gaps and will conduct studies to address special problems identified after major earthquakes.*

Under Objective 3 NEHRP's priorities are to:

- Maintain the *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures.*
- Support *NEHRP Guidelines for the Seismic Rehabilitation of Buildings* and other tools related to existing buildings.
- Support development of guidelines and pre-standards for lifeline systems.
- Start development of next generation performance-based codes.
- Improve coordination of post-earthquake investigations.

The *NEHRP Recommended Provisions* and the related *Commentary* present criteria for designing and constructing buildings subject to earthquakes throughout the U.S. They are resource documents widely used by practicing professionals and building officials. Periodic updates of these documents are critical in order to incorporate results from NEHRP-funded research for immediate use by practicing engineers. FEMA will provide lead support for these periodic revisions, while USGS will support the revision of the underlying probabilistic seismic hazard maps and NIST and NSF will continue to support research and development efforts leading to new cutting-edge methodologies and technologies. NEHRP experts from all four agencies will participate in technical committees responsible for updating the *NEHRP Recommended Provisions* and will work in close coordination with the ICSSC.

The *NEHRP Guidelines for the Seismic Rehabilitation of Buildings* and related *Commentary* are first-of-their-kind, performance-based, nationally applicable design and engineering documents. They contain new approaches, new analytical techniques, choices as to seismic safety levels, and acceptability criteria for upgrading all major types of existing buildings and construction materials. FEMA led the development of this document and will continue to ensure these documents are kept current. This work, and the updates to the *NEHRP Recommended Provisions* discussed above, will be accomplished with existing funding.

Lifelines are another high priority area for NEHRP. FEMA, in partnership with non-governmental organizations and the private sector, has initiated the processes of developing consensus guidelines for lifelines. The goal of this effort is to achieve an acceptable level of seismic performance for these structures, building upon current seismic provisions, as appropriate. To date, efforts to develop the technical basis for performance-based standards, codes, and practices for infrastructure lifeline systems pale in comparison to similar efforts directed at guideline development for new and existing buildings. NEHRP therefore recognizes the need to significantly expand efforts in this area. FEMA will lead this effort and will be assisted by NIST.

Looking to the future, NEHRP supports the need to develop a new generation of performance-based provisions for new buildings and lifelines. Performance-based provisions will encourage/permit competition through value-added products and services, adoption and use of innovative technologies, selection of design or rehabilitation performance level based on owner/user needs, and setting of risk-adjusted insurance premiums commensurate with the chosen performance level. FEMA will lead this effort, and NIST will assist FEMA with problem-focused R&D in developing the technical basis for performance-based standards, codes, and practices for buildings. NIST work will include application of probabilistic and reliability analysis methods underpinning performance-based provisions in coordination with the risk analysis and loss estimation work under Goal C. NSF will continue to support basic research in performance-based earthquake engineering and probabilistic methods through its existing programs.

Major earthquakes provide a unique source of information on the performance of the built environment and failure mechanisms at full scale. Post-earthquake investigations are thus critical for documenting structural performance, examining the adequacy of current standards and practices, and identifying research needs to mitigate the impacts of future earthquakes. NEHRP has long supported post-earthquake investigations, both in the engineering and earth science disciplines. However, improved coordination is necessary if these investigations are to maximize learning through the sharing of information. Therefore, NEHRP, under the leadership of the USGS, will spearhead an examination of the roles and responsibilities of the various groups involved in post-earthquake investigations and will develop a NEHRP protocol action plan for investigations following major national and international earthquakes. This protocol action plan will detail the degree of coordinated learning desired and how it will be achieved and how findings can be most effectively disseminated to all stakeholders (e.g., in a comprehensive, multidisciplinary NEHRP report). The plan will improve coordination during post-earthquake investigation efforts, minimize duplication, and provide safety training for participants.

Goal C. Improve Seismic Hazard Identification and Risk Assessment Methods, and Their Use

Seismic hazard identification and risk assessment are critical components of NEHRP's earthquake mitigation strategy. Under this goal, NEHRP agencies identify and quantify seismic hazards through improved seismic monitoring and through detailed geological and geophysical characterization of regions of active faulting. The seismic hazard information then becomes the foundation upon which subsequent risk assessment models are based. NEHRP will continue to emphasize geological, geophysical, and seismological research activities that improve the state of knowledge of seismic hazard identification. NEHRP will also continue to develop and improve the HAZUS loss estimation tool and work with state and local governments to ensure that this tool is used effectively to guide pre-earthquake mitigation efforts.

1. Provide rapid, reliable information about earthquakes and earthquake-induced damage.

> *NEHRP will continue to support the operation of regional data centers, the National Earthquake Information Center (NEIC), the Global Seismic Network (GSN), the International Seismic Centre (ISC), and the IRIS Data Management Center (DMC). In addition, NEHRP will deliver rapid, accurate reports on the intensity and distribution of strong ground shaking in urban areas following damaging earthquakes. NEHRP will also propose to implement the ANSS.*

Under Objective 1 NEHRP's priorities are to:

- Continue support for global, national, and regional seismic monitoring networks and associated data centers.
- Propose implementation of the Advanced National Seismic System (ANSS).
- Develop improved algorithms for rapidly determine earthquake source parameters (e.g., location, size, type of faulting, direction of fault rupture) and estimating earthquake damage patterns through the production of shaking intensity maps (ShakeMaps).

Seismic monitoring serves as a primary source of information necessary for seismic hazard assessments. USGS has the assigned Federal responsibility to monitor seismic activity in the U.S. The USGS fulfills this role by operating the U.S. National Seismograph Network (USNSN), the National Earthquake Information Center (NEIC), the National Strong Motion Program (NSMP), and by supporting sixteen regional networks in areas of moderate to high seismic activity. Additionally, NSF and USGS operate the Global Seismic Network, which provides the main source of worldwide earthquake information, and NSF also operates archival and distribution centers: the International Seismic Center and the IRIS Data Management Center. NEHRP will continue to maintain and operate these networks and data centers and will improve their integration and real-time reporting capabilities.

Traditionally earthquake monitoring in the U.S. has focused on the identification of areas of active faulting. Recent technological advances, however, are contributing to a broadening in emphasis to include strong motion recording of ground shaking and building response in seismically active urban areas. The data resulting from these efforts are critical to engineering research directed at improving design standards so that structures and systems are better able to withstand the effects of earthquakes. To provide useful, high quality data that meet the needs of engineers, a significant upgrade of the current networks as well as a major expansion of new instrumentation in urban areas is required. The specifications of such a system, referred to as the Advanced National Seismic System (ANSS), have been developed through discussions with the engineering community and summarized in USGS Circular 1188 at the request of Congress. The report calls for over 6000 new instruments in at-risk urban areas, including 3000 strong motion instruments on the ground and an additional 3000 instruments in structures. In addition, the report calls for 1000 broadband stations in regional networks across the Nation. ANSS has received widespread endorsement in the earthquake community and is a high priority for NEHRP.

An important new earthquake-reporting tool that builds on ANSS is ShakeMap. ShakeMap utilizes network recordings of seismic energy to portray the intensity of ground shaking in the region surrounding a significant earthquake. It can thus provide an estimate of earthquake damage patterns and impact within minutes of an event. This information, in turn, can be used by emergency managers to speed earthquake disaster relief. ShakeMap is now being implemented in networks across the country, but for it to be truly effective, it must be supported by a modern seismic network with real-time, high fidelity recordings of the type envisioned in ANSS. Currently the only regional network in the U.S. that offers this capability is in southern California.

Another, longer-range research effort that builds on the technological capabilities of ANSS is the development of an early warning capability for earthquakes already in progress. Specifically, USGS scientists are now exploring the possibility of developing faster means of detecting and characterizing large earthquakes. If large earthquakes can be discriminated from small earthquakes at the onset of rupture, it might be possible—in the special case where the earthquake source is distant to an urban center—to provide an alert of imminent strong ground shaking. Although such a system would offer only a few seconds to tens of seconds of early warning, this brief period may be sufficient to secure critical facilities and prepare for the arrival of strong ground shaking.

2. Improve seismic hazard characterization and mapping.

NEHRP will improve hazard assessment methods and produce updated national-scale ground-shaking maps and related products on a regular basis. NEHRP will also work with cooperators to develop a standard methodology for production of large-scale seismic hazard maps for urban regions.

Under Objective 2, NEHRP's priorities are to:

- Maintain and update national hazard maps through the collection and integration of geologic, geophysical, and seismological data, including prehistoric earthquake chronologies, location of active faults, determination of 3-D velocities and geologic structure, and wave propagation and attenuation parameters.

- Improve probabilistic methods for quantifying seismic hazards, including formally incorporating uncertainty into hazard estimates, especially for areas of relatively low seismicity, such as the East and Intermountain West.

- Produce prototype urban seismic hazard maps for select major metropolitan areas.

The USGS, with support from NSF, has lead NEHRP responsibility for the production of probabilistic seismic hazards maps in the U.S. The first generation of these maps, released in 1996, has been incorporated into updates of the International Building Code, and the information is used by numerous consulting companies to estimate earthquake losses for insurance companies, pension funds, and other clients. Going forward, the USGS will produce an updated set of these maps and associated databases for the contiguous U.S. and will develop new maps for U.S. Trust territories, including American Samoa, Guam, the Northern Mariana Islands, and Puerto Rico/Virgin Islands. The revised national maps will incorporate an updated earthquake catalog with consistent magnitudes, improved ground-motion attenuation relations for the Central and Eastern U.S., and improved knowledge of earthquake source zones and recurrence rates. This work will be completed with existing funds.

Concurrent with the updating of the hazards maps, USGS- and NSF-supported scientists will conduct research on ways to improve probabilistic and scenario methods for quantifying seismic hazards, including identifying and testing alternative methodologies for earthquake-potential estimates. Research efforts will also be directed at formally incorporating uncertainty into hazard estimates. Using existing funding, efforts in this area will focus on areas of relatively low seismicity, such as the East and Intermountain West.

Another key focus area of NEHRP is urban seismic hazard mapping. The increasing valuation of building stock and infrastructure assets, combined with demographic shifts toward earthquake-prone cities, are combining to increase loss potential dramatically for the next urban earthquake. To aid metropolitan areas in evaluating and mitigating this risk, USGS will work with local communities in three test areas (Oakland, Seattle, and Memphis) to develop a standard methodology for urban hazard mapping in three contrasting tectonic environments (strike-slip, subduction, and intraplate faulting, respectively). In these regions, the USGS will collaborate with state geologists, state agencies, and local committees to compile digital surficial geology maps, ground shaking amplification maps, and liquefaction, lateral spreading, and landslide susceptibility maps. The USGS will also determine priorities for subsequent studies in other seismically active urban areas.

3. Support development and use of risk and loss assessment tools.

NEHRP will support improvement of loss estimation and risk assessment tools and the development of next generation databases. Testing and dissemination of the nationally applicable loss-estimation model will continue. States and communities will be encouraged to provide detailed data on local geology, building inventories, and utility and transportation systems to enable more accurate planning and establishing of priorities.

Under Objective 3, NEHRP's priorities are to:

- Provide HAZUS training and support for users.

- Devise standards and protocols that can be implemented to aid in data base enhancements and data collection efforts.

- Continue to improve the usability, functionality, and accuracy of HAZUS. Calibrate and refine HAZUS loss-estimation models following actual damaging earthquakes.

- Integrate ShakeMap with HAZUS to allow for rapid loss estimations.

The main NEHRP focus under Objective 3 is the continued development and promotion of Hazards U.S. (HAZUS), a FEMA GIS-based loss estimation tool designed to aid in mitigation planning and disaster response activities. HAZUS provides a standardized approach to estimating losses from earthquakes and other hazards and utilizes the national seismic hazard maps developed by the USGS as well as complementary information on the built environment to assess risk. Although HAZUS has been used by FEMA to estimate annualized earthquake losses nationally across the U.S. (FEMA #366, Sept. 2000), it also offers the capability of computing more detailed loss estimates for major urban centers. Communities across the country are anxious for this capability; however, additional developmental components must be completed before use will be widespread.

First, there is a universal need for additional training and guidance in the use of HAZUS. This is a high priority for NEHRP and FEMA will lead in this effort. Second, there is a need for development of data collection standards, tools, and storage formats to enable consistent, accurate, and effective augmentation of the national data-bases with more detailed local information such as building inventories, lifeline inventories, and local site response estimates. The USGS and FEMA will cooperate with local users to establish these standards and protocols. It is important to note, however, that NEHRP is not capable of performing detailed data acquisition efforts at a local scale. This will be the responsibility of states and local communities. Third, there is a general need to improve the usability, functionality, and reliability of HAZUS and to calibrate with post-earthquake assessments following major damaging earthquakes. Finally, if HAZUS is to be used in a rapid response mode, it must be modified to incorporate the near real-time intensity ground shaking information portrayed in the USGS's ShakeMap routine. The USGS and FEMA are working on adding this capability, thereby permitting rapid, automatic calculations of loss estimation to aid in both the response and recovery processes. Widespread use of such features, however, will ultimately require modern seismic monitoring instrumentation of the type envisioned by ANSS. Use of these features, in coordination with local and federal GIS capability, has the potential to significantly move the state of the practice forward.

Goal D. Improve The Understanding of Earthquakes and Their Effects

Activities under Goal D comprise the basic research component of NEHRP and cover a range of disciplines from geology and seismology, to earthquake engineering and structural engineering, to the behavioral and economic sciences. USGS and NSF are the two primary NEHRP agencies supporting Goal D efforts, with USGS emphasizing the geologic and seismologic disciplines and NSF also supporting these areas in addition to studies of the built environment and the behavioral and economic impact of earthquakes. Activities in Goal D are inherently intermediate- to long-term research efforts that may not yield immediate payoffs. Past experience suggests, however, that these efforts will contribute significantly to future risk mitigation efforts.

The following sections address current and future NEHRP activities under each of the six objectives of Goal D.

1. Improve monitoring of earthquakes and earthquake-generating processes.

> *NEHRP will continue to develop improved seismic monitoring capabilities geared toward full-waveform recording, real-time reporting, and improved network integration. NEHRP also will continue to support and expand other monitoring systems and the use of satellite-based observational systems for monitoring the deformation of the earth's crust due to earthquakes and earthquake-generating processes.*

Seismicity and crustal deformation monitoring provides a wealth of critical information for research into fault identification, slip rate estimates, and hazard assessments. Earthquake monitoring also contributes to engineering investigations of building and infrastructure response and soil-structure interactions for earthquake design purposes. NEHRP is continually seeking ways to improve monitoring and reporting technologies and thereby enhance real-time reporting efforts while delivering ever-improving information for downstream research efforts into hazard assessments and earthquake engineering. (Note that seismic monitoring activities are presented in detail under Goal C.1. We thus incorporate that section by reference and limit this discussion to crustal deformation monitoring.)

Under Objective 1, NEHRP's priorities are to:

- Maintain crustal deformation monitoring in active seismic areas of California, the Pacific Northwest, the Central U.S., Nevada, Utah, and Alaska for understanding the strain fields associated with earthquakes.

- Establish a Plate Boundary Observatory consisting of a network of GPS, and deformation sensors (GPS, strain meters) across the Western U.S.

- Investigate Interferometric Synthetic Aperture Radar (InSAR) techniques for providing map images of fault slip, areal crustal deformation associated with earthquakes, and rapid post-earthquake damage assessment.

Even in the most seismically active parts of the U.S., aseismic movements account for the majority of crustal deformation. For this reason, USGS and NSF-supported researchers monitor crustal deformation across seismically active regions using a range of instrumentation (e.g., leveling and laser-ranging surveys, strain meters, and Global Positioning System (GPS) sensors). The measurement of aseismic deformation includes determination of the plate motion rates that drive earthquakes in California, Oregon, Washington, and Alaska, of strain rates in interplate areas of the U.S., as well as the recording of small transient strain signals associated with fault motion that may be related to earthquake generation.

Recent advances in technology and large decreases in the cost of instrumentation have enabled continuous determinations of positions at fixed GPS sites, providing a practical way to continuously track crustal deformation. A number of continuous GPS monitoring stations currently exist in concentrated areas of study across the western U.S., and NSF is now proposing to expand and integrate these networks into a single strain observatory that extends across the entire North American–Pacific plate boundary (i.e., from the Rocky Mountains to the Pacific Ocean). This Plate Boundary Observatory (PBO) will permit NEHRP scientists to measure the rate and distribution of strain buildup and release before, during, and after earthquakes, and determine how deformation is accommodated three-dimensionally within the plate boundary zone.

In addition to GPS-based deformation monitoring, NEHRP is supporting research into new technologies for satellite-based monitoring of crustal deformation. In particular, both NSF and USGS are working cooperatively with NASA to explore the capabilities of satellite-based InSAR techniques in mapping small changes in ground deformation. Large areal maps of the ground deformation will give clear images of deformation accompanying and following large earthquakes. The technology may also elucidate regional strain accumulation around faults between earthquakes.

Funding for PBO and InSAR are being proposed under NSF's EarthScope initiative, which was advanced in FY 2002 as a Major Research Equipment and Facilities Construction Project (MREFC).

2. Improve understanding of earthquake occurrence and potential.

NEHRP will support research into the processes by which earthquakes occur, including studies of how large earthquakes initiate and grow, the role of fault zone geometry and mechanical properties, and the effect of changes in earth stresses.

Seismic hazard assessments rely upon estimates of the locations, sizes, and probabilities of future earthquakes. These estimates, in turn, require identifying the physical variables that govern where and how often earthquakes occur and how large they will be. NEHRP supports a range of studies directed at understanding these variables through investigations into earthquake rupture, recurrence, stress transfer, aftershock activity, and remote triggering.

Under Objective 2, NEHRP's priorities are to:

- Investigate the rupture process of large earthquakes, including the initiation, propagation, and arrest of seismic rupture and test the resulting hypotheses by geologic, geodetic, seismological, and other relevant field observations, laboratory experiments, and numerical simulation.

- Use geodetic and geologic techniques to determine crustal strain rates, compare these strain rates with long-term seismic moment release, fault slip rates, and modeled plate rates, and investigate how all of these quantities are related to future earthquake potential. Evaluate the validity of the "characteristic earthquake" model.

- Acquire laboratory measurements of physical properties, rock/fluid compositions, temperature, stress, and pore pressure in active fault zones under *in situ* conditions.

- Establish the San Andreas Fault Observatory at Depth (SAFOD) and use it as an *in situ* laboratory for measuring and monitoring fault zone properties at depth across the San Andreas Fault.

Research into the fundamental physics of large earthquakes is being supported by NSF and USGS through an array of laboratory, field, and theoretical investigations of seismicity, fault zone properties, and crustal strain. These studies are directed at understanding earthquake nucleation, propagation, arrest, and recurrence and include research into fault zone geologic or geometric heterogeneity, frictional properties, deformation rates, rupture histories, wave propagation, fault segmentation, measured strain rates, stress concentrations, and mechanical and chemical effects of pore fluids. These studies will continue to be supported at current levels.

A future priority for NEHRP is the creation of the San Andreas Fault Observatory at Depth (SAFOD), an *in situ* laboratory for measuring and monitoring the San Andreas Fault. SAFOD is designed to facilitate direct measurements of fault zone properties where aseismic creep and small earthquakes occur. By monitoring the fault zone prior to, during, and after an earthquake, SAFOD will provide answers to a number of fundamental questions about the physical and chemical processes responsible for earthquake generation. Funding for SAFOD is being proposed under NSF's EarthScope initiative, which was advanced in FY 2002 as a Major Research Equipment and Facility Construction Project.

3. Improve earthquake hazards assessments and develop earthquake-potential estimates as planning scenarios.

NEHRP will support a broad-based research program on earthquakes and ground failure by improving quantification and understanding of the extent of hazards and by encouraging use of that knowledge for planning purposes.

National and regional hazard assessments require integration of information from nearly all aspects of earthquake hazards research as well as the information collected by the seismic and crustal strain monitoring networks. These activities are described under Goal C. Future improvements in the quality of hazard assessments depend on new insights derived from these seismological and geological research efforts.

Under Objective 3, NEHRP's priorities are to:

- Enhance modeling of large earthquakes to incorporate realistic physical constraints and fault behavior.

- Model the likely impact of anticipated great earthquakes on large urban regions, using realistic scenarios. Validate results from earthquake studies with results from structural and engineering investigations.

While peak accelerations in great earthquakes are not expected to be significantly larger than they are in the near-source region of moderate-to-major earthquakes, great earthquakes cause very long duration shaking (several minutes) and very large long-period ground motions. Neither long shaking durations nor large long-period ground motions have been experienced by modern U.S. cities, and their effects are poorly understood. Although the likelihood of a great earthquake in an urban center is certainly much smaller than a moderate earthquake, there is precedent for such events (e.g., 1906 San Francisco and 1923 Tokyo earthquakes) and scenario models are needed to assess their potential impact.

New research results from these fundamental earthquake studies can have enormous benefits in better understanding the response of structures and lifelines to the large ground motions of big earthquakes. It is therefore essential that results of these fundamental earthquake studies be shared with the geotechnical and engineering communities. The information provided by large earthquakes elsewhere in the world in various tectonic settings provides results that are valuable for validation and improvement of design and planning standards in the U.S.

4. Improve fundamental knowledge of earthquake effects.

NEHRP will support research on the nature of strong ground shaking from earthquakes, how it is affected by seismological and geological factors, and how its characteristics are related to permanent ground deformation and damage. These efforts will include investigations of damage from domestic and foreign earthquakes and collaboration with non-U.S. research programs.

Among the most important contributions of NEHRP to reducing earthquake losses in the U.S. are improving the understanding and modeling of damaging earthquake effects. These effects include strong ground shaking, failure and deformation of unstable ground, and the impact of these geologic effects on the built environment. NEHRP research into earthquake effects is thus directed at both the geophysical parameters controlling ground shaking and ground deformation and their relationship to structural damage through studies of soil-structure interaction.
Under Objective 4, NEHRP's priorities are to:

- Develop improved methods to generate synthetic seismograms for expected future earthquakes, incorporating improved understanding of the rupture process and information about the fault and the properties of the surrounding earth's crust. Test 3-D numerical simulations of basin response to strong shaking.

- Record strong seismic shaking for large earthquakes and develop synthetic models that match the observed. Acquire recordings by implementing a national strong motion instrumentation program for structures and ground-based sites, and by conducting post-earthquake investigations.

- Identify the parameters of ground motion that cause liquefaction and slope instability and damage to structures (such as acceleration, velocity, shaking duration, and spectral content). Develop techniques to estimate the permanent ground deformation and displacement resulting from earthquake-induced landslides and liquefaction. Improve understanding of soil-structure interaction and examine the response of structures and lifelines.

Studies of strong ground shaking and earthquake effects require knowledge of the earthquake source, the propagation of seismic energy from the source to the site, and the local geologic conditions that characterize the site. For this reason, USGS and NSF support a broad spectrum of research ranging from studies of earthquake source properties to near-field effects, wave-propagation effects, local site effects controlling ground failure, and correlation of ground motion parameters to structural and lifeline response. NSF also supports research on engineering methods to mitigate the effects of the ground motion on new and existing structures and lifelines. Collectively these research activities address the primary factors controlling the magnitude of earthquake losses and casualties through their effects on structures and lifelines.

Synthetic seismograms are an outgrowth of these studies and are used to model building and lifeline response and guide their design. A priority for NEHRP is the development and refinement of synthetic seismogram modeling techniques to produce more accurate ground motion time histories. The seismograms must accurately simulate a number of parameters used by structural and geotechnical engineers, including peak acceleration, ground velocity and displacement, response spectra, and shaking duration.

Large and destructive earthquakes provide the best opportunities to substantially advance the understanding of earth science and engineering issues associated with earthquake effects. But to capitalize on this learning opportunity, instruments capable of capturing the complete seismic signal must be in place. This is one of the reasons NEHRP is proposing to implement an Advanced National Seismic System, which would include approximately 3000 strong motion instruments capable of full-waveform recording in critical structures, facilities, and buildings across the Nation. These instruments will provide heretofore unavailable data on structural response to strong shaking that is absolutely essential for advancing earthquake-engineering practices.
The other means of obtaining strong motion recordings is through post-earthquake investigations. NEHRP will thus continue to respond to damaging domestic earthquakes with

portable seismic instrumentation, geodetic measurements, geologic field investigations, and damage evaluations. USGS will take the lead in coordinating these post earthquake response efforts, following the guidelines outlined in the post earthquake response action plan called for under Goal B. In the case of foreign earthquakes, NEHRP will cooperate with U.S. and foreign institutions in focused investigations directed at filling critical knowledge gaps in fault behavior, site effects, and soil-structural interaction.

Landsliding, liquefaction, and lateral spreading are major contributors to earthquake destruction. An improved understanding of subsurface conditions and ground failure mechanisms is necessary if losses in this area are to be reduced. Advances in this area require improved measurements and instrumentation. Monitoring of physical properties, pore pressure, acceleration, and other transient parameters are all necessary to characterize the ambient physical properties of the soils in which failure occurs. Such measurements will enable NSF-supported researchers and USGS scientists to develop techniques designed to estimate earthquake-induced permanent ground deformation and displacement.

Studies of nonlinear soil response are critical for assessing site-specific shaking hazards. The NSF earthquake engineering research centers actively support research in this area, and there are ongoing projects by other NSF-funded investigators that are focused on the prediction of site response under large earthquakes for which soil behavior may not be elastic. The NEES equipment portfolio will include experimentation equipment that will extend our knowledge in this area.

5. Advance earthquake engineering knowledge of the built environment.

> *NEHRP will implement the Network for Earthquake Engineering Simulation (NEES) to improve the seismic design and performance of U.S. civil and mechanical infrastructure systems through collaborative and integrated experimentation, computation, theory, databases, and model-based simulation.*

NEHRP supports research in earthquake engineering through NIST and NSF. The problem-focused research and development conducted by NIST to improve codes, standards, and practices for buildings and lifelines is discussed under Goal B. The NSF-supported research is directed at developing new knowledge derived from fundamental research on buildings, lifelines, geologic materials, and geotechnical construction. NSF research activities also address the impacts of seismic events on the physical infrastructure systems that serve the public and societal institutions.

Under Objective 5, NEHRP priorities are:

- Improve the understanding of existing materials and develop new materials and technologies for earthquake resistant structures. Develop and validate new structural systems and new methods of structural control.
- Improve the understanding of collapse mechanisms of various classes of structures. Enhance the understanding of fragility curves for various classes of buildings and utility

and transportation lifelines to improve performance-based earthquake engineering methodologies.

- Focus research efforts on theoretical simulations of building and lifeline "systems" through the implementation of NEES. Research how structure and component integration change the performance of the overall structure. Conduct post-earthquake investigations to validate and calibrate research results.

A new facet of earthquake engineering research now being launched by NSF is theoretical studies of the structural response of the built environment to earthquakes based on computer simulations. This effort, known as the Networked Earthquake Engineering Systems (NEES), will transform earthquake engineering research from its current reliance on physical experiments to investigations based on integrated experimentation, computation, theory, databases, and model-based simulation. Research areas to be supported under NEES include: structural control, composite and hybrid seismic structural systems, smart materials and structures to develop new building systems, advanced technologies for seismic response reduction and control, and health monitoring. NSF also supports experimental and model-based research projects in these areas. The NEES project will exploit Internet technology to integrate and interconnect nationally distributed facilities. NEES will also provide a curated data repository for easily accessible information, and the managing NEES consortium will develop outreach, educational, and experimental opportunities for the professional community.

As the network of NEES facilities comes on line in FY 2004, university-based research is important to provide maintenance and operation support for the NEES facilities and to support the expanded research opportunities made possible by the NEES project.

6. Advance understanding of the social and economic implications of earthquakes.

NEHRP will support earthquake-related social science and policy research to advance understanding of the social and economic impacts of earthquakes, determine levels of risk deemed acceptable by various groups in society, and reduce the social, economic, and political barriers to effective earthquake risk reduction.

The social science community has the potential to make vital contributions to NEHRP as it moves forward. Social scientists can, for example, research effective ways to involve communities in risk identification, prevention, and mitigation; communicate earthquake risks to targeted audiences; evaluate the effectiveness of existing and proposed programs and policies; and assess and improve the design and operations of organizations and institutions whose job it is to prepare for, respond to, mitigate, and aid in recovery from earthquakes. This work can serve to increase the pace and overall success of NEHRP risk-reduction measures. Currently NSF provides funding for interdisciplinary university-based research conducted in the social, economic, policy, and decision sciences, in addition to research contributions from engineering and natural sciences. In addition, the NSF-funded earthquake engineering research centers develop strategic research agendas that include interdisciplinary research framed to integrate contributions from social and natural sciences and engineering, with applications to performance-based earthquake engineering, seismic risk mitigation, pre-earthquake preparedness, and post-earthquake response and recovery. This work will continue and will be more directly integrated into the NEHRP activities outlined in other portions of the plan.

Under Objective 6, NEHRP priorities are to:

Analyze how incentives influence risk-reduction behavior under the conditions of uncertainty inherent with earthquake predictions. Research ways to expand and improve incentives to promote earthquake mitigation.

- Analyze risk perceptions and their effects on decision making in order to develop a common framework for discussing risk with engineers, building owners, occupants, and public officials. Improve techniques for explaining risk under conditions that have varied degrees of uncertainty.

- Research effective means to communicate real-time warnings to various intended recipients so that appropriate responses are elicited. Incorporate research results into the development of earthquake early notification systems.

Improving earthquake risk communication requires continued investment in both fundamental research and translation of that research into risk communication and management policies and practices. While we now understand a good deal more about risk perceptions than we did several decades ago, research on the relationship between risk perceptions and mitigation decisions, and on risk communication and management, may enable risk reductions as large as or larger than equal investments in physical and engineering sciences.

NSF supports research by social and behavioral scientists that will improve our understanding of how different incentives influence behavior under conditions of uncertainty. Research should be supported on the direct and indirect effects of a range of incentives for hazard mitigation, including taxes and other financial incentives, social and legal sanctions, and land-use based incentives. NSF also supports research on risk analysis and management as well as on the design of effective institutions, which can help to identify potentially effective policies and organizational strategies for achieving risk reduction. The policy implications of the results of this research should be identified and evaluated. If, for example, specific kinds of financial incentives are identified by researchers as potentially effective at encouraging large and small businesses, organizations, government agencies, and individuals to implement mitigation programs, FEMA could support Federal and state tax consultants to identify the specific changes in existing Federal and state tax policies that would accomplish this.

We are not currently able to measure and quantify risks and discuss them within a common framework used by engineers, building owners, occupants, and public officials. Early work was conducted in the field of risk perception and communication, however, further research in the decision sciences field is needed to enable policy makers to communicate relative risks under conditions that have varied degrees of uncertainty in terms of time, place, magnitude, and frequency, while taking into consideration the limitations of engineering knowledge.

Technological developments have made real-time warning systems a potential tool to communicate warnings to affected groups: the general public, large and small businesses, emergency responders, hospitals, and schools systems. However, we do not have an adequate understanding of how best to communicate these warnings in a way that is fast, reliable, and generates the appropriate response from each recipient. NSF supports research by social scientists to understand how warning information is processed and acted upon and how transmission modes and messages are linked to behavioral response. USGS will such research results into the development of earthquake early notification systems.

Implementation Summary

The table below summarizes the range of implementation activities proposed under this strategic plan. NEHRP program managers will work with agency policy officials through the NEHRP Policy Coordination Council, and with the Office of Management and Budget and Congress to develop detailed plans and budget justifications for these projects.

Table 1. Summary of planned implementation activities.

Goal A. Develop effective practices and policies for earthquake loss reduction and accelerate their implementation. 1. Develop and provide information on earthquake hazards and loss-reduction measures to decision-makers and the public. 2. Promote incentives for public and private sector loss-reduction actions. 3. Advocate state and local government practices and policies that reduce losses in the public and private sectors. 4. Implement policies and practices that reduce vulnerability of Federal facilities. 5. Develop the Nation's human resource base in the earthquake field.			
Goal and Objective	**NEHRP Activity**	**Lead Agency**	**Support Agencies**
A.1	Distribute NEHRP resource materials and provide technical advice to promote adoption of risk reduction measures to decision makers and the public.	FEMA	NIST NSF USGS
A.2	Promote loss reduction actions through development of partnerships and incentives with local communities and businesses.	FEMA	NSF USGS
A.3	Advance seismic risk reduction at the state and local government level through interaction with, and support of, state-based advisory bodies.	FEMA	USGS NSF
A.3	Promote the adoption of building codes at the state and local levels.	FEMA	USGS NSF
A.4	Reduce the risk to existing and future Federal facilities, in cooperation with the ICSSC, through development and adoption of risk-reduction standards for Federal agencies.	FEMA NIST	USGS NSF
A.5	Support curricula and education programs for K-12 and university students.	FEMA NSF	USGS NIST
A.5	Provide training and continuing education through partnerships for the use of NERHP technical resources developed under Goals B, C, and D.	FEMA USGS	

Goal B. Improve techniques to reduce seismic vulnerability of facilities and systems. 1. Facilitate technology transfer among standards organizations, state and local governments, and private-sector professionals. 2. Improve earthquake loss-reduction knowledge and the quality of practice 3. Support efforts to improve seismic standards and codes and improve design and construction practices for buildings and lifelines.			
Goal and Objective	**NEHRP Activity**	**Lead Agency**	**Support Agencies**
B.1	Support development of improved building codes and encourage technology transfer through consortia and professional trade associations.	FEMA	NIST
B.2	Expand the use of problem-focused research to support a new generation of codes and standards for buildings and lifelines.	NIST	FEMA NSF
B.3	Maintain NEHRP guidance documents for new and existing buildings.	FEMA	USGS
B.3	Develop performance-based codes for buildings and lifelines.	FEMA NIST	NSF USGS
B.3	Improve coordination of post-earthquake investigations.	USGS	FEMA NIST NSF
B.3	Develop integrated, comprehensive NEHRP post-earthquake reports and databases.	USGS	FEMA NIST NSF

Goal C. Improve seismic hazards identification and risk assessment methods, and their use.

1. **Provide rapid, reliable information about earthquakes and earthquake-induced damage.**
2. **Improve seismic hazard characterization and mapping.**
3. **Support development and use of risk and loss assessment tools.**

Goal and Objective	NEHRP Activity	Lead Agency	Support Agencies
C.1	Operate national, regional, and global seismic networks and associated network information centers.	USGS NSF	
C.1	Upgrade seismic monitoring networks through the implementation of the ANSS.	USGS	
C.2	Update and expand national seismic hazard maps, including U.S. trust territories. Incorporate new earth science data and improve probabilistic methods.	USGS	NSF
C.2	Develop prototype urban seismic hazard maps for select major metropolitan areas.	USGS	
C.3	Expand access to HAZUS and provide necessary training.	FEMA	
C.3	Support development of standards for database management and data collection efforts.	FEMA	NSF USGS
C.3	Refine HAZUS earthquake model to incorporated new research findings and database developments and calibrate with post-earthquake studies.	FEMA	USGS

Goal D. Improve the understanding of earthquakes and their effects. 1. Improve monitoring of earthquakes and earthquake-generating processes. 2. Improve understanding of earthquake occurrence and potential 3. Improve earthquake hazards assessments and develop earthquake-potential estimates as planning scenarios. 4. Improve fundamental knowledge of earthquake effects. 5. Advance earthquake engineering knowledge of the built environment. 6. Advance understanding of the social and economic implications of earthquakes.			
Goal and Objective	**NEHRP Activity**	**Lead Agency**	**Support Agencies**
D.1	Expand and advance crustal deformation monitoring, including investigation of GPS and Interferometric Synthetic Aperture Radar techniques.	NSF	USGS NASA
D.1	Establish and support Plate Boundary Observatory in western U.S.	NSF	USGS
D.2	Continue earth science studies and research related to earthquake potential and earthquake occurrence.	USGS NSF	
D.2	Establish and support the San Andreas Fault Observatory at Depth (SAFOD).	NSF	USGS
D.3	Model the likely impact of anticipated large earthquakes on urban regions and refine results using structural and engineering investigations.	NSF	USGS
D.4	Develop improved methods to predict ground shaking and structural damage. Evaluate effect of nonlinear soil response on urban areas. Calibrate results through post-earthquake investigations.	USGS NSF	
D.4	Develop techniques to estimate ground deformation from landslide and liquefaction.	NSF USGS	
D.5	Improve knowledge of structural characteristics and system performance of constructed facilities.	NSF	NIST
D.5	Advance earthquake engineering knowledge of the built environment through implementation of NEES.	NSF	
D.6	Support interdisciplinary research that involves engineering, natural science, and social, economic, and decision sciences.	NSF	FEMA USGS NIST

Program Management / Agency Coordination

Program management requires a programmatic agenda, or implementation plan, that identifies the projects, schedules, responsible agencies, and resource commitments and that describes the involvement of each agency. Management of this Plan is shared by the NEHRP agencies on a collegial basis. Each agency represents its own interests and remains responsible for its own programs, but recognizes the value of cooperative actions. As the lead agency, FEMA is ultimately responsible for program and policy matters but solicits advice from the Interagency Coordination Council (ICC). The ICC is responsible for writing, adopting, and implementing this Strategic Plan, and for integrating agency programs to accomplish the Plan's goals and objectives. Periodic meetings provide a forum for discussing common activities, exploring crosscutting issues, collaborating on joint projects, identifying and resolving conflicts, and seeking support and cooperation. The ICC also provides a mechanism for revising the Strategic Plan.

The ICC will conduct an annual program review at which the project managers will present achievements and reports on their projects. This meeting will have two purposes. The first is to permit the ICC to assess progress and to redirect efforts to take advantage of new results. The second purpose is to allow the agency representatives to gain insight into the work of the other agencies and to facilitate collaboration among them.

The NEHRP agencies have identified several explicit areas where resources and funding will be specifically coordinated:

- Meetings of Policy Coordination Council (PCC)
- Meetings of Interagency Coordination Council (ICC)
- Developing an explicit research implementation process
- Post-earthquake coordination
- Coordinated audience identification/information dissemination/Internet presence
- Coordination of EERCs and multi-state consortia activities and funding
- Guidelines for external partnering

The following discussions outline in more detail the specific areas of coordination listed above.

The PCC, consisting of the head of FEMA's Mitigation Division, and the directors of NIST, NSF, and USGS, will meet on at least a bi-annual basis. The focus of their meetings will be high-level policy issues that concern strategic NEHRP direction and liaison with the Office of Management and Budget and Congress.

The ICC, chaired by the Director of FEMA's Engineering and Technology Unit, and populated with a representative from NIST, NSF, and USGS, will meet on at least a quarterly basis throughout the year. The key focus of the ICC will be interagency coordination of projects, programs, plans, budgets, and operational NEHRP issues. Some of the key purposes of these regularly held meetings are for each of the program agencies to present their NEHRP-related budget and expense figures and to have a better understanding of what activities each agency is emphasizing. These meetings also will act as a catalyst for spurring interagency cooperative projects.

An extremely high priority in the short term for NEHRP is the improvement of the "research to practice to implementation" cycle, especially in the building sciences area. There currently exists a fundamental disconnect in that there is not a clear link for research results to be incorporated into codes and standards development and implementation activities. The result is that relevant research activities take longer to get translated into practice. Similarly, research needs identified by guideline development and implementation activities are not being communicated to research organizations; hence, these items are not being investigated in a timely manner. An exception has been the incorporation of USGS and NSF data on the national hazard maps into the model building codes. This is an example where the cycle appears functional and has worked well. The NEHRP agencies need to develop and agree on a conceptual flowchart and process to close this loop. This will be accomplished by a NEHRP research issues ad hoc working group that will have the responsibility of designing mechanisms and processes that assure proper information transfer and coordination.

Another area that requires attention is post-earthquake investigations. Following an earthquake, there is a tremendous opportunity to both learn and to transmit findings. Following the 1964 Alaska and 1971 San Fernando earthquakes, significant government efforts produced comprehensive reports on the respective earthquakes. Since that time, the scientific landscape has changed. A large number of groups now embark on post-earthquake reconnaissance and data collection efforts and produce reports. However, there is insufficient coordination or synergy to these efforts. By creating a pre-earthquake action plan for post-earthquake coordination, NEHRP's goal is to produce a framework, with stakeholder input, that maximizes the efficiency and minimizes the overlap of these efforts.

Coordinated audience identification is a key component of any effective effort by the NEHRP agencies to raise earthquake awareness and encourage mitigation activities. It is critical for NEHRP to coordinate internally so that it speaks to the community in a common voice. This is especially important during post-earthquake response efforts and requires improved coordination among the various field offices of FEMA, NSF, and USGS.

The NEHRP agencies will form an ad hoc information dissemination working group that seeks to eliminate overlap in agency dissemination efforts and to better coordinate resources in existing efforts. One area of immediate focus will be the development of a NEHRP web site that serves as an information source about NEHRP agency activities and other program information. FEMA will assume the lead for this effort.

The NEHRP agencies provide significant funding to the EERCs (MAE, MCEER, and PEER) through NSF. In addition, FEMA and USGS fund multi-state consortia such as the Central US Earthquake Consortium (CUSEC), the Western States Seismic Policy Council (WSSPC), the New England States Emergency Consortium (NESEC), and the Cascadia Region Earthquake Workgroup (CREW). Historically, each of the NEHRP agencies has funded these entities separately, presenting a challenge to coordinate the efforts of these groups to meet NEHRP objectives. The NEHRP agencies will promote the joint coordination of the activities of these groups and will develop coordination in annual reviews. This will help avoid duplicative efforts. It will also force better coordination between the centers and consortia in meeting NEHRP objectives.

Finally, as an aid to Plan revisions, NEHRP will convene an ad hoc stakeholder group comprised of a balanced and representative sampling of NEHRP stakeholders. This group will have a revolving membership and will aid the ICC in revising the Strategic Plan by providing opinions and firsthand observations of what is needed on the ground to ensure more efficient earthquake loss reduction.

Measuring Performance

Measuring the progress of earthquake mitigation is inherently problematic. Those who seek to quantify the value of mitigation efforts face a frustrating dilemma—it's the actions that aren't taken that lead to measurable consequences, while the actions that are taken are subject to ambiguity. Did the structure survive because of retrofitting, or because the shaking intensity and duration of the earthquake were not sufficiently strong to cause damage? If the building codes had not been strengthened, what would have been the impact of an event? It is extremely difficult to measure events that have not yet occurred, but that is nevertheless the challenge.

The Earthquake Hazards Reduction Act of 1977 and the NEHRP mission statement contain two complementary, fundamental goals: 1) to develop knowledge and, 2) to promote practices and policies to reduce fatalities, injuries, and economic and other losses. As they are distinctly different tasks, different methods of measuring performance need to be employed.

Developing Knowledge

Evaluating the *outcomes* of the research component of NEHRP requires a science-sensitive approach. Research under NEHRP is intended to fulfill program goals as well as to address a national goal of leadership in scientific knowledge. Basic research is intended to advance knowledge—it is not required that it produce tangible, immediately useful results, although this often happens. NEHRP activities are focused to expand fundamental understanding of earthquake processes, engineering, and social and economic impacts. This knowledge is further developed through applied research and development activities that enable effective transfer of the new applications, methods, and technologies to those who will use it in reducing earthquake losses.

A performance assessment for research and development activities should include continuous self-assessment and periodic external independent review of the outcomes and quality of research. Of importance to the NEHRP mission, the review should: 1) evaluate the excellence of the research methods and products; 2) determine how rapidly research results are translated for use in reducing risk; 3) assess how effectively earthquake scientists, engineers, and practitioners learn from other areas of research and from other nations; 4) assess how investigators apply new knowledge and use it in advancing their own research and development efforts; and 5) analyze the effectiveness and appropriateness of allocation of research resources by discipline and NEHRP priorities. Recommendations from such evaluations can be used to improve the effectiveness of the research, development, and implementation programs in meeting the Nation's science objectives and the NEHRP goals and objectives. Conclusions from such reviews should be included in NEHRP reports to Congress.

Reducing Losses

The second component of measuring performance is measuring the effectiveness of the program in the reduction in earthquake losses. Damaging earthquakes occur only infrequently, which makes difficult the validation of the predicted or expected reductions in earthquake losses as a result of NEHRP activities. NEHRP could work to develop HAZUS loss estimates over 5-year time intervals to estimate the likely reductions in earthquake losses in selected areas of the country. However, the logistical difficulties required to assemble this data make this path impractical. An alternative approach is the development of risk indicators that can serve as proxy measures of the success of loss-reduction activities. Input will be required from the stakeholder communities to identify meaningful metrics, and to evaluate the usefulness of candidate metrics. Program metrics developed should be subjected to periodic review to ensure that the target indicator is being accurately represented, and should incorporate the results of continuing research in the field.

Next Steps

Development of metrics for a program as diverse and difficult to measure as the NEHRP program will require careful thought and effort. It is critical that metrics be designed that are meaningful, that will accurately reflect the performance measures of interest, and that will actually measure the two key program objectives, developing knowledge and reducing losses. To develop the desired metrics, the NERHP agencies will commit resources in FY03 to developing a series of metrics consistent with each NEHRP agencies' GPRA reporting requirements for both the developing knowledge and reducing losses missions of NEHRP.

Appendix A. Development of Implementation Plan

The development of the implementation sections of this strategic plan began with a stakeholder workshop in September of 1999. Workshop participants were identified by goal so that broad representation was assured. Discussion of implementation activities occurred in four concurrent discussion sessions corresponding to the four NEHRP Goals. Discussion leaders were appointed, and these same leaders were responsible for producing summary reports of recommended implementation activities following the meeting discussion.

The next step in the process was for a working subgroup of the ICC to categorize the existing NEHRP activities by goal and objective. This list was then compared to the list of proposed implementation activities generated from the September 1999 workshop. Areas where suggested implementation activities were matched by ongoing activities within the agencies were left alone, while gaps (i.e., those areas where suggested activities represented new or expanded efforts not currently being addressed within NEHRP) were specifically identified. The agencies then prioritized these proposed activities on the basis of perceived value and need, and on the fit with stated NEHRP goals and objectives. High priority activities were then summarized by goal and objective into a draft document that was distributed to all the participants of the September 1999 workshop.

The distribution of the draft plan was followed by a second workshop in September 2000. At this meeting, a summary of the major changes to the document was presented. Breakout sessions corresponding to the four Strategic Plan goals were again assembled to discuss in detail the recommendations under each goal contained in the latest version of the plan. Also, topical discussions on stakeholder involvement and program metrics were undertaken in the breakout groups. Comments were collected in the breakout groups and presented in a general plenary session. A considerable question and answer period was also employed as a feedback mechanism. The ICC Working group then took the feedback from the second workshop and incorporated relevant comments into the plan. At this juncture, the document was reformatted to reflect the forward-looking nature of NEHRP and to sharpen the focus of the Plan’s message. The Working Group prepared final revisions, and the plan was submitted to the agencies for formal internal review in early November 2000.

Appendix B. List of Workshop Participants

<u>September 1-2, 1999</u>

Daniel P. Abrams	Mid-America Earthquake Center
Jim Ament	State Farm Fire and Casualty Co.
Jill Andrews	University of Southern California
Walter Arabasz	University of Utah
Michael Armstrong	FEMA
James E. Beavers	Mid-America Earthquake Center
Richard Bernknopf	USGS
Ann Bostrom	NSF
Jawhar Bouabid	Durham Technologies, Inc.
James Buika	FEMA
Arrietta Chakos	City Managers Office, Berkeley, CA
Harish Chander	Department of Energy
Karen Clark	Applied Insurance Research
Craig Comartin	Comartin-Reis
James Davis	California Division of Mines & Geology
Gregory Deierlein	Stanford University
Claire Drury	FEMA
Charles D. Eadie	University of California
Donald Eggleston	SERA Architects PC
Richard Eisner	Office of Emergency Services, CA
Steven P. French	Georgia Institute of Technology
John Filson	USGS
Arthur D. Frankel	USGS
Edward S. Fratto	NESEC
Ian Friedland	MCEER
Marjorie R. Greene	EERI
John Gross	NIST
Robert Hanson	FEMA, University of Michigan
Ronald Hamburger	EQE International
James R. Harris	JR Harris & Company
Jack Hayes	US Army Construction Engineering
Thomas Heaton	CALTECH
Gregory L. Hempen	USACE, St. Louis District
Gil Jamieson	FEMA
Arch Johnston	CERI, University of Memphis
Rob Johnson	Cascadia Region Earthquake Workgroup
Gerald H. Jones	National Institute of Building Sciences
John D. Kiefer	Kentucky Geological Survey
Anne S. Kiremidjian	Stanford University
Elizabeth Lemersal	FEMA
H.S. Lew	NIST
Theodore Litty	FEMA

Sue Luebbering-Evers	FEMA
Edgar V. Leyendecker	USGS
Ronald Lynn	Clark Co. Nevada Bldg. Dept.
George Mader	Spangle Associates
Stan Mahin	University of California, Berkeley
Mike Mahoney	FEMA
Bob McCluer	BOCA International
Thomas R. McLane	ASCE
Mike Mehrain	Dames & Moore
Ugo Morelli	FEMA
Sam Morton	The Morton Company
Priscilla Nelson	NSF
Joanne Nigg	University of Delaware
Stuart Nishenko	FEMA
Robert A. Olson	Robert Olson Associates, Inc.
Ronald Padgett	Kentucky Division of Emergency Management
Joy Pauschke	NSF
Milo Pearson	California Earthquake Authority
Chris Poland	Degenkolb Engineers
Jonathan G. Price	Nevada Bureau of Mines and Geology
Joseph Rachel	FEMA
Robert Reitherman	CUREe
Michael Riley	NIST
Christopher Rojahn	Applied Technology Council
Paul Senseny	Factory Mutual Insurance
Daniel Shapiro	SOHA Engineers
Haresh Shah	Stanford University
Tim Sheckler	FEMA
Paul G. Somerville	URS Greiner Woodward Clyde
Shyam Sunder	NIST
Bruce Swiren	FEMA
Alex Tang	Nortel
Mary Taylor	FEMA
Thomas Tobin	Tobin and Associates
Susan K. Tubbesing	EERI
Jerry Uhlmann	Missouri State Emergency management Agency
Anita Vollmer	FEMA
Yumei Wang	Oregon Dept. of Geology and Mineral Industries
James Whitcomb	NSF
Stephen Weiser	Idaho Bureau of Disaster Services
Stuart Werner	Seismic Systems and Engineering Consultants
Soy Williams	International Code Council, Inc.
Craig Wingo	FEMA
Cecily Wolfe	NSF
T. Leslie Youd	Bringham Young University
Eugene Zeller	Long Beach Department of Planning

Robert Zimmerman	Boeing Company

<u>September 6-7, 2000</u>

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John G. Anderson	University of Nevada
Michael Armstrong	FEMA
James E. Beavers	Mid-America Earthquake Center
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Ian Buckle	University of Nevada, Reno
Jim Buika	FEMA
Charles D. Eadie	University of California
Donald Eggleston	SERA Architects PC
John Filson	USGS
Edward S. Fratto	NESEC
Jayanta Guin	Applied Insurance Research
Marjorie R. Greene	EERI
Robert Hanson	FEMA, University of Michigan
James R. Harris	JR Harris & Company
Jack Hayes	US Army Construction Engineering
Thomas Heaton	CALTECH
Gregory L. Hempen	USACE, St. Louis District
Jon Janowitz	FEMA
Rob Johnson	Cascadia Region Earthquake Workgroup
Gerald H. Jones	National Institute of Building Sciences
John D. Kiefer	Kentucky Geological Survey
Anne S. Kiremidjian	Stanford University
Elizabeth Lemersal	FEMA
Mark Leonard	California Earthquake Authority
Theodore Litty	FEMA
Sue Luebbering-Evers	FEMA
Edgar V. Leyendecker	USGS
George Mader	Spangle Associates
Mike Mahoney	FEMA
Jill McCarthy	USGS
Thomas R. McLane	ASCE
Mike Mehrain	Dames & Moore
Jack Moehle	PEER, University of California, Berkeley
Ugo Morelli	FEMA
Priscilla Nelson	NSF
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Dennis Olmstead	Oregon Dept. of Geology and Mineral Industries
Robert A. Olson	Robert Olson Associates, Inc.
Chris Poland	Degenkolb Engineers
Jonathan G. Price	Nevada Bureau of Mines and Geology

Michael Riley	NIST
Christopher Rojahn	Applied Technology Council
Richard Roths	FEMA
William U. Savage	Pacific Gas & Electric Company
Paul Senseny	Factory Mutual Insurance
Daniel Shapiro	SOHA Engineers
Tim Sheckler	FEMA
Howard Simpson	Simpson Gumpertz & Heger, Inc.
Paul G. Somerville	URS Greiner Woodward Clyde
Shyam Sunder	NIST
Craig Taylor	Natural Hazards Management, Inc.
Susan K. Tubbesing	EERI
Jerry Uhlmann	Missouri State Emergency management Agency
Anita Vollmer	FEMA
Soy Williams	International Code Council, Inc.
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