Strategic Plan

for the

National Earthquake Hazards Reduction Program

Fiscal Years 2022–2029

April 2023

This Strategic Plan for the National Earthquake Hazards Reduction Program (NEHRP) for Fiscal Years 2022–2029 has been developed by the Program Coordination Working Group and approved by the Interagency Coordinating Committee (ICC) on Earthquake Hazards Reduction. This plan is required by the Earthquake Hazards Reduction Act of 1977 (Public Law 95-124, 42 U.S.C. 7701 *et. seq.*), as amended by the NEHRP Reauthorization Act of 2018 (Public Law 115-307).

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Executive Summary

This Strategic Plan for the National Earthquake Hazards Reduction Program (NEHRP or Program) for Fiscal Years 2022–2029 has been developed by the Program Coordination Working Group and approved by the Interagency Coordinating Committee on Earthquake Hazards Reduction. This plan is required by the Earthquake Hazards Reduction Act of 1977 (Public Law 95-124, 42 U.S.C. 7701 *et. seq*.), as amended by the NEHRP Reauthorization Act of 2018 (Public Law 115-307).

NEHRP is a coordinating program for earthquake monitoring, research, implementation, education, and outreach activities developed and conducted by the NEHRP agencies. These agencies are:

- the Federal Emergency Management Agency;
- the National Institute of Standards and Technology;
- the National Science Foundation; and
- the U.S. Geological Survey.

NEHRP Strategy for Seismic Risk Reduction

The NEHRP agencies have established four coordinated strategic goals and eighteen supporting strategic objectives that support the Program policy, vision, and mission. The strategy outlined establishes a specific integrated and coordinated approach for the development and accomplishment of Program activities to support seismic risk reduction.

The national policy for the Program is to:

> *Strengthen the security and resilience of the nation against earthquakes, to promote public safety, economic strength, and national security*—Executive Order 13717

The Program vision is:

> *A nation that is ready and capable to withstand, respond to, and recover from earthquakes and their consequences*

The Program mission is to:

> *Develop, advance, and disseminate knowledge, tools, practices, and policies to enhance the nation's capabilities to withstand, respond to, and recover from earthquakes and their consequences*

The goals and objectives are:

Goal 1: *Advance the understanding of earthquake processes and their consequences.*

Goal 1 and its objectives support the Program's responsibility to advance the physical science, social science, and engineering knowledge associated with earthquakes. They address programmatic efforts to advance our knowledge of earthquake generation mechanisms and energy propagation within the Earth. They further support fundamental disciplinary and interdisciplinary research needs to better comprehend changes to and the distribution of seismicity and seismic hazards, as well as to identify the consequences of earthquakes—both geological effects and impacts on society, the economy, and the built environment. The fundamental outcome of Goal 1 is seismic hazard and risk characterization related to earthquakes. Goal 1 forms the basis for targeted fundamental and applied research efforts by the Program in Goal 2.

- Objective 1: Advance the understanding of earthquake phenomena and the propagation of seismic energy.
- Objective 2: Advance the characterization of the nation's seismicity, including sources, and seismic hazards.
- Objective 3: Advance seismic monitoring including improving, extending, and maintaining the Advanced National Seismic System and the Global Seismographic Network.
- Objective 4: Advance the understanding of the consequences of earthquakes and associated hazards to society and the built environment.
- Objective 5: Advance the understanding of social, behavioral, and economic factors, including equity, pertinent to implementation of earthquake preparedness, mitigation, and recovery strategies.

Goal 2: *Enhance existing and develop new information, tools, and practices for protecting the nation from earthquake consequences.*

Goal 2 and its objectives support the Program's responsibility to support and conduct targeted fundamental and applied disciplinary and interdisciplinary research, risk assessments, and problem-focused studies. They address programmatic efforts to develop mitigation practices that can reduce earthquake consequences on society, the economy, and the built environment. The fundamental outcome of Goal 2 is to advance effective preparedness and mitigation strategies to support earthquake readiness and risk reduction capabilities. Goal 2 forms the basis for implementation efforts by the Program in Goal 3.

- Objective 6: Enhance current earthquake scenarios, risk assessment methodologies, and loss estimation tools to improve seismic risk information.
- Objective 7: Further develop and implement a West Coast earthquake early warning system and its associated communication, education, and outreach.
- Objective 8: Enhance and develop cost-effective tools and practices, including up-to-date building codes and national consensus standards, that improve the seismic performance of new and existing buildings and lifeline infrastructure.
- Objective 9: Advance knowledge to facilitate characterization of earthquake resilience and

develop tools to measure successful implementation of resilience practices and policies.

Goal 3: *Promote the dissemination of knowledge and implementation of tools, practices, and policies that enhance strategies to withstand, respond to, and recover from earthquakes.*

Goal 3 and its objectives support the Program's responsibility to transfer knowledge and promote the adoption and implementation of earthquake risk reduction measures. They address programmatic efforts to disseminate tools (e.g., seismic hazard maps and risk assessment models), develop guidelines on earthquake safety, and support implementation of mitigation strategies through building codes, standards, and policies. Goal 3 commits the Program to working to ensure that information and tools are designed in ways that are useful to stakeholders and to support the implementation of effective earthquake preparedness and risk reduction practices and policies. The fundamental outcome of Goal 3 is promotion of Program products to enhance preparedness and risk communication strategies that improve the nation's ability to withstand, respond to, and recover from earthquakes. Goal 3 forms the basis for evaluation efforts by the Program in Goal 4.

- Objective 10: Enhance the accuracy, timeliness, usefulness, and accessibility of earthquake information products for a diverse range of users to better prepare for and respond to earthquakes.
- Objective 11: Implement and regularly update a National Seismic Hazard Model based on the latest research, source models, seismicity, and field studies, essential for implementing state-of-the-art mitigation, design, and construction strategies.
- Objective 12: Actively engage in the continual development and use of up-to-date seismic design guidelines, standards and building codes, and advocate for their adoption and enforcement at the state, local, tribal, and territorial level.
- Objective 13: Support and enhance earthquake education, emergency drills, and exercises to promote effective earthquake awareness as well as mitigation, response, and recovery planning.
- Objective 14: Promote the implementation of earthquake preparedness, safety, response, and recovery strategies, which account for social, behavioral, and economic factors, including equity.

Goal 4: *Learn from post-earthquake investigations to enhance the effectiveness of available information, tools, practices, and policies to improve earthquake resilience.*

Goal 4 and its objectives support the Program's responsibility to ensure that important lessons are drawn from post-event analyses. They address programmatic efforts to evaluate existing strategies to systematically characterize lessons learned from previous events, which in turn support improvements in earthquake resilience. The fundamental outcome of Goal 4 is that related data and outcomes provide feedback to the efforts conducted under Goals 1, 2 and 3, ensuring continual improvement in Program activities.

- Objective 15: Maintain and advance Program-wide procedures and policies for post-earthquake investigations and data acquisition management.
- Objective 16: Advance earthquake preparedness, safety, response, and recovery strategies by translating post-earthquake investigation results into approaches for improved resilience.
- Objective 17: Identify and take advantage of opportunities to collaborate on development of scientifically informed metrics and actions to evaluate community earthquake resilience after an earthquake, which account for social, behavioral, and economic factors, including equity.
- Objective 18: Provide mechanisms to promote relevant feedback to the public regarding lessons learned from earthquakes.

Program-Identified Focus Areas to Support NEHRP

The NEHRP agencies have identified eight focus areas that address issues with serious public need coupled with impactful opportunities for innovation and advancement toward seismic risk reduction. These focus areas are as follows, not ranked in any order of priority:

1. Advance earthquake science for subduction zone regions.
2. Develop enhanced performance-based seismic design procedures and metrics for the functional recovery of new and existing buildings and lifeline infrastructure.
3. Advance performance-based seismic design and assessment methods to implement multi-system coordination.
4. Further expand earthquake early warning capabilities.
5. Develop consistent performance guidance for lifeline infrastructure.
6. Enhance guidance to ensure that information and tools effectively support the needs of those who implement mitigation, preparedness, and recovery measures.
7. Advance the science of earthquake sequence characterization.
8. Enhance risk reduction strategies for federal agencies.

This Strategic Plan provides an executable strategy for NEHRP to support its mission. The Plan reflects congressional requirements and is intended to guide the development and implementation of programmatic activities by the Program agencies. Attaining these strategic goals will enable increased earthquake resilience throughout the nation by improving life safety, reducing economic losses, and minimizing security, mission, or functional disruptions resulting from future earthquakes.

Chapter

1

Introduction

The National Earthquake Hazards Reduction Program

Earthquakes are among the greatest natural hazards faced by the United States, with the potential of significant damage to the built environment resulting in deaths and injuries, economic losses, and debilitating impacts to the social fabric of affected regions. According to a 2006 National Research Council (NRC) report[1], 42 states have some degree of seismic risk and 18 of those states have areas of high seismicity. In addition, all U.S. territories in the Pacific Ocean and Caribbean Sea are subject to earthquakes. About half the population in the U.S. resides in areas with moderate to high earthquake hazard[2] (see Figure 1-1). The NRC report notes that the estimated value of structures in all states prone to earthquake damage is approximately $8.6 trillion (2003 dollars[3]). Earthquakes cannot be prevented, but their impacts on life, property, and the economy can be mitigated.

Congress first authorized the National Earthquake Hazards Reduction Program (NEHRP) in 1977 in the Earthquake Hazards Reduction Act (EHRA) (42 U.S.C. § 7702) to "reduce the risks of life and property from future earthquakes in the United States." Congress oversees NEHRP in part through a periodically recurring reauthorization process. The most recent reauthorization of the EHRA was Public Law 115-307 in December 2018; it is linked from Appendix D.

NEHRP is a coordinating program for earthquake monitoring, research, implementation, education, and outreach activities developed and conducted by the NEHRP agencies. These agencies are:

- the Federal Emergency Management Agency (FEMA);
- the National Institute of Standards and Technology (NIST);
- the National Science Foundation (NSF); and
- the U.S. Geological Survey (USGS).

[1] *Improved Seismic Monitoring, Improved Decision Making—Assessing the Value of Reduced Uncertainty*, National Research Council, 2006.
[2] *The Role of the NEHRP Recommended Seismic Provisions in the Development of Nationwide Seismic Building Code Regulations: A Thirty-Five-Year Retrospective*, FEMA P-2156, Federal Emergency Management Agency, 2021.
[3] Based on the Consumer Price Index, the 2003 cost would translate to approximately $14 trillion in 2022 dollars.

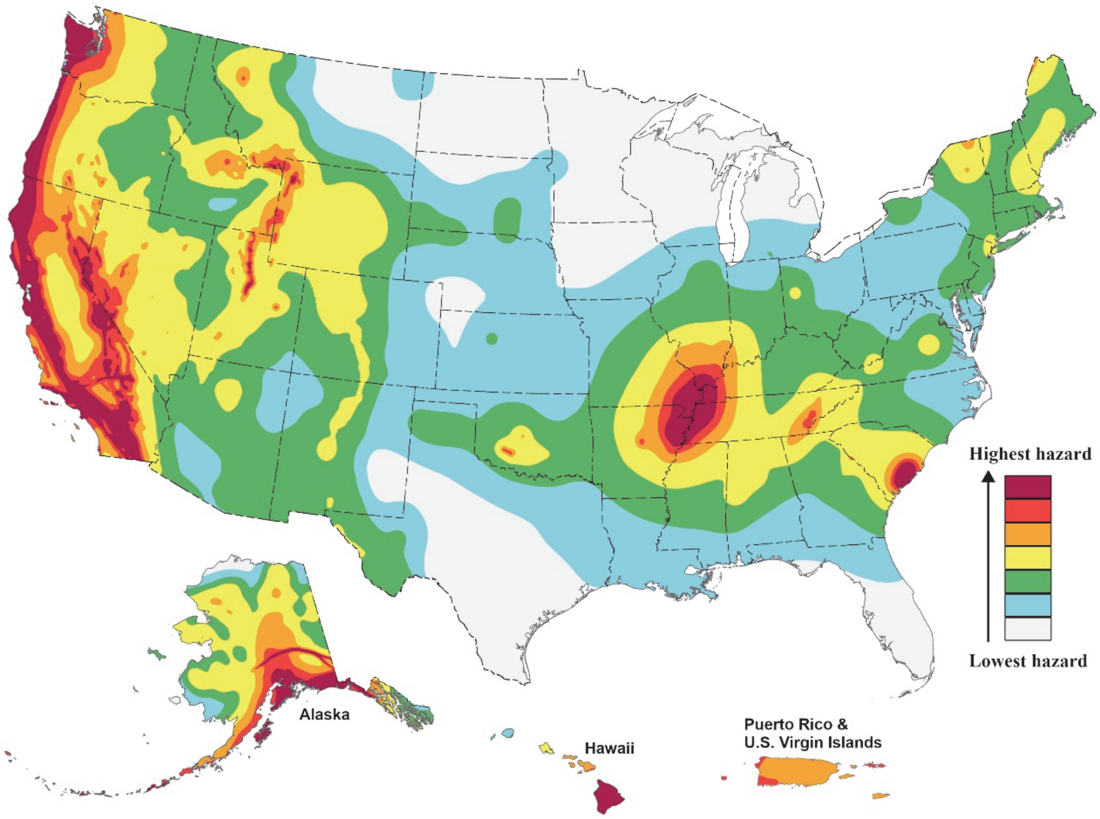


Figure 1-1. The USGS National Seismic Hazard Maps show 42 states with some degree of earthquake risk. This map is based on the most recent USGS hazard models for the conterminous U.S. (2018), Hawaii (2021), Alaska (2007), and Puerto Rico (2003). Data from these maps are incorporated into seismic provisions of model building codes, one of the ways that NEHRP translates knowledge into practice. Maps for other territories are available from the USGS website. Image courtesy of USGS.

NEHRP, or the Program, is a somewhat unusual interagency federal program, with no single congressional appropriation and relies upon cooperation between the Program agencies. The Program also has no regulatory authority, thus, although it works to influence earthquake-resilient building codes and practices, it cannot dictate or enforce national standards. NEHRP must rely on research, data collection, and analyses to produce relevant results and products that will be adopted and used by stakeholders to mitigate public and private earthquake risks. Accomplishments of the Program are dependent on the actions and cooperation of the four agencies whose missions are complementary and compatible with the needs of the Program. The agencies' earthquake related missions, which were outlined in the prior two NEHRP strategic plans[4,5], are summarized below (more detail is provided in Appendix B):

[4] *Expanding and Using Knowledge to Reduce Earthquake Losses—The National Earthquake Hazards Reduction Program, Strategic Plan 2001–2005*, FEMA 383, Federal Emergency Management Agency, 2003.
[5] Strategic Plan for the National Earthquake Hazards Reduction Program, FY2009-2013 (2008).

- FEMA translates results from earthquake research and problem-focused studies into guidance, training, and support services. FEMA works with national model codes and consensus standards groups to promote better earthquake-resistant design guidance and aids in the development of performance-based seismic design guidelines and methods. FEMA assists states in developing mitigation, preparedness, and response plans, supports comprehensive earthquake education and awareness, and establishes demonstration projects on earthquake hazard mitigation.
- NIST serves two functions within NEHRP. First, NIST is the NEHRP lead agency and thus is responsible for planning and coordinating the Program. Second, NIST conducts and supports earthquake research and development to provide new or enhanced earthquake-resistant design provisions for building codes and standards, advance seismic-resistant construction practices, and enhance measurement and prediction tools supporting performance-based seismic design and community resilience.
- NSF supports fundamental research in computer and information sciences, engineering, geosciences, as well as social, behavioral, and economic sciences relevant to the understanding of the causes and consequences of earthquakes. NSF supports advanced earthquake engineering and geoscience research facilities, centers, and cyberinfrastructure, as well as the integration of research, education of the future workforce, and outreach to professionals and the public.
- USGS conducts and supports geoscience research and investigations on earthquake causes and effects, produces national and regional seismic hazard maps and assessments, monitors and rapidly reports on earthquake occurrences and their potential impacts, and works to improve public understanding of earthquake hazards. USGS is the lead agency for post-earthquake investigations and thus coordinates logistics and response to significant domestic earthquakes by the NEHRP agencies and other organizations.

The Interagency Coordinating Committee on Earthquake Hazards Reduction that is composed of the principals of the four NEHRP agencies, the Office of Management and Budget, and the Office of Science and Technology Policy oversee NEHRP. The Advisory Committee on Earthquake Hazards Reduction assesses the Program. More information is provided in Appendix B.

Reducing the seismic risks posed to the nation by earthquakes is a government-wide effort, of which NEHRP is one component. The success of the whole federal effort will be contingent upon integrated and collaborative roles between the NEHRP agencies, their partners, and inter-programmatic coordination with other relevant federal programs, rooted in a common vision and shared mission.

The Challenge

Severe earthquakes, with potentially catastrophic consequences, occur infrequently in the United

States, but they can strike without warning. The United States has been fortunate in that a catastrophic earthquake has not occurred in over 25 years. Consequently, public concern and related preparedness and mitigation actions tend to diminish within the seismic lulls between major earthquakes, thus making the challenge for NEHRP of preparing our society for infrequent, high impact earthquakes even greater.

While not characterized as catastrophic, several more recent moderately-sized earthquakes have resulted in significant economic losses and disruptions of services. The magnitude (M) 7.1 Anchorage, AK earthquake on November 30, 2018 resulted in estimated losses of approximately $100 million due to damages. Damages in the 2019 Ridgecrest, CA earthquake sequence over July 4th and 5th were estimated to be over $5 billion[6]. The Puerto Rico earthquake sequence, which began in late December 2019 and was punctuated by a M6.4 earthquake on January 6, 2020, resulted in a large population being displaced from their homes and a $3.1 billion estimate of direct and indirect economic losses[7]. Even locations that have relatively low seismicity have experienced disruptions from earthquakes. The M5.8 Mineral, VA earthquake on August 23, 2011 essentially shutdown normal operations within the Washington, D.C. metropolitan area for a few days and resulted in $200 million in damages. The challenge for NEHRP is to move beyond just a life safety performance target and develop and support approaches to minimize economic losses from physical damages and interruption of government, commerce, communications, housing, and supporting services.

The NRC report and a report published by the Earthquake Engineering Research Institute (EERI)[8] concluded that direct economic costs due to physical damage within the built environment and indirect economic costs from business interruptions in a future major earthquake that strikes a large urban area could easily exceed $100 billion (2003 dollars). The accompanying injuries and deaths would make this impact more severe. This estimate is even more plausible when several issues that were raised in the EERI report, distilled in the following paragraphs, are considered:

- Growth in population, economies, and societal interconnectedness have led to significant increases in lives and infrastructure at risk and to ever larger areas affected by "local" disasters. For example, earthquake damage to a major West Coast container shipping port or to vital river crossings (bridges, pipelines) in the central U.S. would result in significant disruptions to the national economy, possibly weakening U.S. competitiveness in the world economy and posing a threat to national security.
- Urbanization in most of the seismically active areas in the United States has led to greater potential damage in those areas[9]. Although detailed damage cost comparisons are not available,

[6] *Ridgecrest Quake Damage Estimated Above $5 Billion at Massive China Lake Naval Base*, Aug. 14, 2019 Los Angeles Times. https://www.latimes.com/california/story/2019-08-14/billions-earthquake-damage-china-lake-naval-base.

[7] https://earthquake.usgs.gov/earthquakes/eventpage/us70006vll/executive

[8] *Securing Society Against Catastrophic Earthquake Losses: A Research and Outreach Plan in Earthquake Engineering*, Earthquake Engineering Research Institute, January 2003.

[9] USGS Circular 1188, *An Assessment of Seismic Monitoring in the United States: Requirement for an Advanced National Seismic System*, identifies 26 U.S. urban areas at significant earthquake risk.

the consequences of urbanization are evident from a comparison of the 1971 San Fernando, California, and 1994 Northridge earthquakes, which were of similar magnitude. In 2007 dollars, San Fernando caused approximately $3 billion in losses and Northridge caused $45–$55 billion in losses. Although not all this difference can be attributed to societal changes over time, increased urbanization leads to higher risk and potential losses.

- Earthquake related design provisions in building codes used in the United States have primarily sought to protect building occupants against loss of life or life-threatening injuries, with the objective (but not a guarantee) of "life safety." Modern building codes address higher performance and functionality requirements for high occupancy facilities (e.g., schools) and essential facilities (e.g., hospitals). Still, code-compliant buildings may protect their occupants in future earthquakes but are not required to be designed to explicitly limit economic losses or the time needed to recover the services provided within the facility. Similarly, damage to lifeline infrastructure, such as utility generation stations and distribution networks, may not cause direct death or injury, but may result in significant economic losses, a greater population of displaced residents, and delayed emergency response and recovery efforts.
- Earthquake hazards and their impacts are still not fully understood. Every new damaging earthquake provides new knowledge about their impacts and how to guard against future losses. Historically, large earthquakes have occurred in areas such as the Pacific Northwest, Atlantic Coast and Central United States, but there is no firsthand experience in those areas with severe ground shaking and its impact on the modern built environment. In order to devise loss reduction strategies in regions that have not experienced large earthquakes in recent times, results from smaller earthquakes, and large earthquakes in other areas, must be extrapolated to estimate the risks. This leads to large uncertainties in damage and impact assessments, as well as in the public awareness of risk.
- Based on current rates of replacement for buildings and infrastructure, today's building stock, much of which does not comply with modern building codes, will continue to remain in use for decades to come. This is especially true in underserved communities, where building replacements are even lower. The costs of current mitigation technologies for existing structures are often high and effective tools for making decisions about mitigation investments are limited, so widespread adoption of mitigation measures faces significant obstacles.

Additional challenges for the Program stem from advancing beyond the built environment and addressing losses from consequences to society. Mental and physiological health, loss of employment, displacement, interruptions to education, work, childcare, and community services all play a key factor in estimating the true impacts of an earthquake. In addition, mitigation, response, and recovery strategies for earthquakes can be informed by lessons learned from other natural and man-made hazards, the COVID-19 pandemic, and impacts from climate change. Climate change could exacerbate earthquake consequences on the built environment, for example those resulting from increased soil saturation from water level rise (i.e., liquefaction). Because few large magnitude earthquakes have struck the United States since it became highly urbanized, contemporary American society tends to underestimate its true earthquake risk exposure.

The EERI report noted that “our ability to secure society against catastrophic earthquake losses depends on a strong and viable NEHRP.” Reducing the physical, societal, and economic impacts of earthquakes nationwide is the principal purpose of NEHRP. This Strategic Plan has been developed with this purpose in mind.

The NEHRP Strategic Plan

This Strategic Plan provides an executable strategy for NEHRP to support its mission for fiscal years 2022 through 2029. Chapter 2 describes the elements of the NEHRP strategy for seismic risk reduction, including the Program vision, mission, and strategic goals and objectives. Chapter 3 outlines Program-identified focus areas for the Plan period. Appendix A provides abbreviations and acronyms. Appendix B provides an overview of NEHRP today. Appendix C presents an overview of the process used to develop this Plan. Appendix D provides a timeline of key legislation and reauthorizations and a link to the EHRA as amended through the NEHRP Reauthorization Act of 2018.

A supporting Management Plan will be developed based on this document. The Management Plan will present in more detail how the Program will implement the strategy presented in this Plan. This Plan also provides a baseline for measuring progress of the Program and a template for reporting on that progress.

Chapter

2

NEHRP Strategy for Seismic Risk Reduction

This Strategic Plan for NEHRP is built upon four coordinated strategic goals and eighteen supporting strategic objectives that support the Program policy, vision, and mission. The strategy outlined establishes a specific integrated and coordinated approach for the development and accomplishment of Program activities to support seismic risk reduction.

Policy, Vision, and Mission for NEHRP

The national policy for the Program is to:

> *Strengthen the security and resilience of the nation against earthquakes, to promote public safety, economic strength, and national security*—Executive Order 13717

The Program vision is:

> *A nation that is ready and capable to withstand, respond to, and recover from earthquakes and their consequences*

The Program mission is to:

> *Develop, advance, and disseminate knowledge, tools, practices, and policies to enhance the nation's capabilities to withstand, respond to, and recover from earthquakes and their consequences*

The vision conveys the Program's aspiration for its principal impact. The readiness and capability of the nation to counter losses and disruption from earthquakes depends on the actions of individuals, organizations in the private and non-profit sectors, and governmental units at federal, state, and local levels. Thus, to achieve its mission, NEHRP must enable stakeholders to enhance their own decisions and actions.

The mission communicates the role of the Program. Accomplishing the Program mission requires developing and applying knowledge based on research in the geological, engineering, and social sciences, educating leaders and the public, and assisting state, local, tribal, territorial, and private sector leaders to develop and adopt standards, policies, and practices targeted at reducing seismic risks.

Strategic Goals and Supporting Objectives

The four goals are linked in ways that lead logically toward increased earthquake risk reduction nationwide. The goals were constructed to be unique and mutually supportive while integrating the roles and responsibilities of the four Program agencies. The objectives describe specific types of activities that enable progress toward each goal. Details about the development of the goals and objectives are provided in Appendix C.

Goal 1: Advance the understanding of earthquake processes and their consequences.

A mandate of NEHRP is to develop and conduct fundamental disciplinary and interdisciplinary research in the geosciences, engineering, and social sciences on earthquake phenomena, on earthquake consequences, and on means to reduce earthquake impacts. The NEHRP agencies recognize that this research is essential to form the knowledge base from which targeted fundamental and applied research and mitigation practices and policies can be developed. Research directions include, but are not limited to:

- understand earthquake generation mechanisms and energy propagation within the Earth;
- understand changes to and the distribution of seismicity and seismic hazards;
- identify and study the consequences of earthquakes, including geological effects and impacts on society, the economy, and the built environment;
- apply the science of communication to increase awareness of earthquake dangers in the populations at risk; and
- effective public communication of the economic and societal benefits of adopting seismic risk reduction measures.

The fundamental outcome of Goal 1 is seismic hazard and risk characterization resulting from earthquakes. Goal 1 forms the basis for targeted fundamental and applied research efforts by the Program in Goal 2.

Objective 1 Advance the understanding of earthquake phenomena and the propagation of seismic energy.

The physical processes of earthquakes are complex, requiring laboratory, seismic, geodetic, geologic, and remote sensing observations in order to develop enhanced physics-based models of these processes, including models of seismic energy propagation, deformation, and shaking intensity. An essential component of improved understanding and models is a well-staffed, maintained state-of-the-art earthquake monitoring system.

Outcome: Validated physical models of earthquake processes leading to improved knowledge of earthquake mechanisms and source characterizations, locations, and propagation, which can be used to prioritize and focus Program outputs.

Objective 2 Advance the characterization of the nation's seismicity, including sources, and seismic hazards.

The basis for policies and strategies for preparing for and responding to an earthquake is an understanding of the seismicity and seismic hazard at the location of interest. Seismicity reflects the historic activity in a region, including earthquake location, depth, magnitude, and faulting mechanisms; see Figure 2-1 for an example. Of primary interest to decision-makers is the potential shaking intensity at the surface during an earthquake and the probability that an earthquake of a given intensity will occur within a given time. Fundamental to understanding the seismic performance of the built environment are data on earthquake ground motions directly related to the seismic hazard. An essential function of NEHRP is to characterize the distribution of seismicity and seismic hazards for the nation and describe their changes over time.

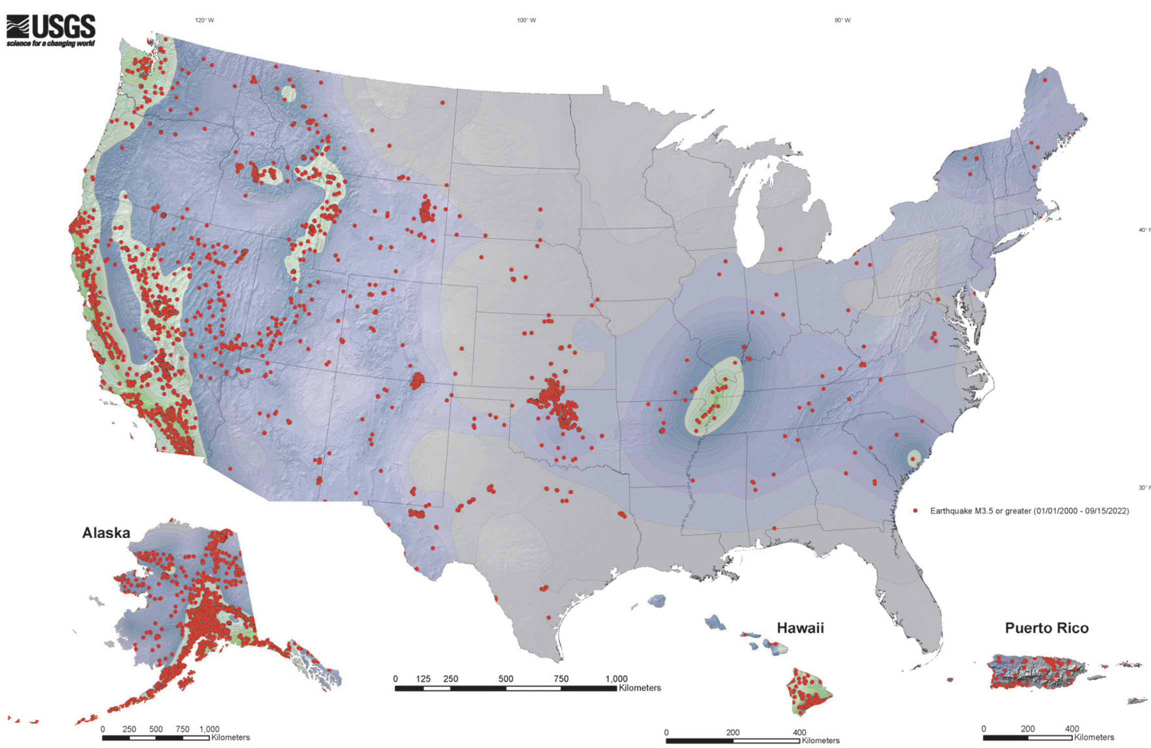


Figure 2-1. Map of M3.5 and larger earthquakes in the contiguous United States, Alaska, Hawaii, and Puerto Rico from Jan. 1, 2000 to August 31, 2022. Background shading illustrates higher hazard regions in the National Seismic Hazard Model, shading aligns with that shown in Figure 1-1. Maps for other territories are available from the USGS website. Image courtesy of Eric Jones, USGS.

NEHRP maintains the National Seismic Hazard Model, which forecasts the likelihood of earthquakes and seismic ground motion (shaking) nationwide and supports the development of national building codes. To remain current, this model must be updated every several years to incorporate results of new research and earthquake activity. For successful information transfer to stakeholders, these updates must be closely coordinated with the earthquake professional community.

Outcome: Improved site characterization methodologies and hazard forecasts, which collectively support the development and application of appropriate seismic design and construction practices as well as characterization of the impact potential given population density and built environment characteristics.

Objective 3 Advance seismic monitoring including improving, extending, and maintaining the Advanced National Seismic System and the Global Seismographic Network.

A well-staffed and well-maintained state-of-the-art earthquake monitoring system is critical to supporting Objectives 1 and 2 and is also an essential mechanism for providing real-time data for emergency response and public notification. This system is an essential component in supporting capabilities to accurately forecast and communicate information and data related to the estimated hazard and potential losses resulting from a recorded earthquake. NEHRP maintains the National Seismic Network, a component of the Advanced National Seismic System (ANSS), which further comprises numerous regional seismic networks. NEHRP also operates the Global Seismographic Network (GSN). These networks are composed of modern digital seismic stations that can record the broad range of motions created during an earthquake as shown in Figure 2-2[8]. To improve, extend, and maintain ANSS, reliable and cost-effective sensor and data collection systems are needed to better characterize earthquake sources (e.g., location, magnitude, mechanism) and ground shaking in the built environment. Research and development into procedures and methods to more rapidly, accurately, and completely compute earthquake source parameters are also needed in order to support emergency response applications and long-term hazard assessments. Further, a vital role of the ANSS is integration within an earthquake early warning system, see Goal 2, Objective 7, so activities to support that integration are also needed.

NEHRP also maintains the National Earthquake Information Center (NEIC), which in partnership with ANSS regional networks, provides earthquake information, notifications, and impact assessments on a 24×7 basis. The NEIC is commonly the first-place media outlets go for earthquake information and impact assessment.

Outcome: A standardized, comprehensive, and technologically advanced seismic monitoring and data analysis and collection system that provides high-quality data and information for

[8] USGS (2017). *Advanced National Seismic System: Current Status, Development Opportunities, and Priorities for 2017–2027*.

accurate and timely notification on earthquakes and their impacts worldwide, as well as data for tsunami warning, earthquake hazard and loss assessments, and basic and applied research in seismology and engineering.

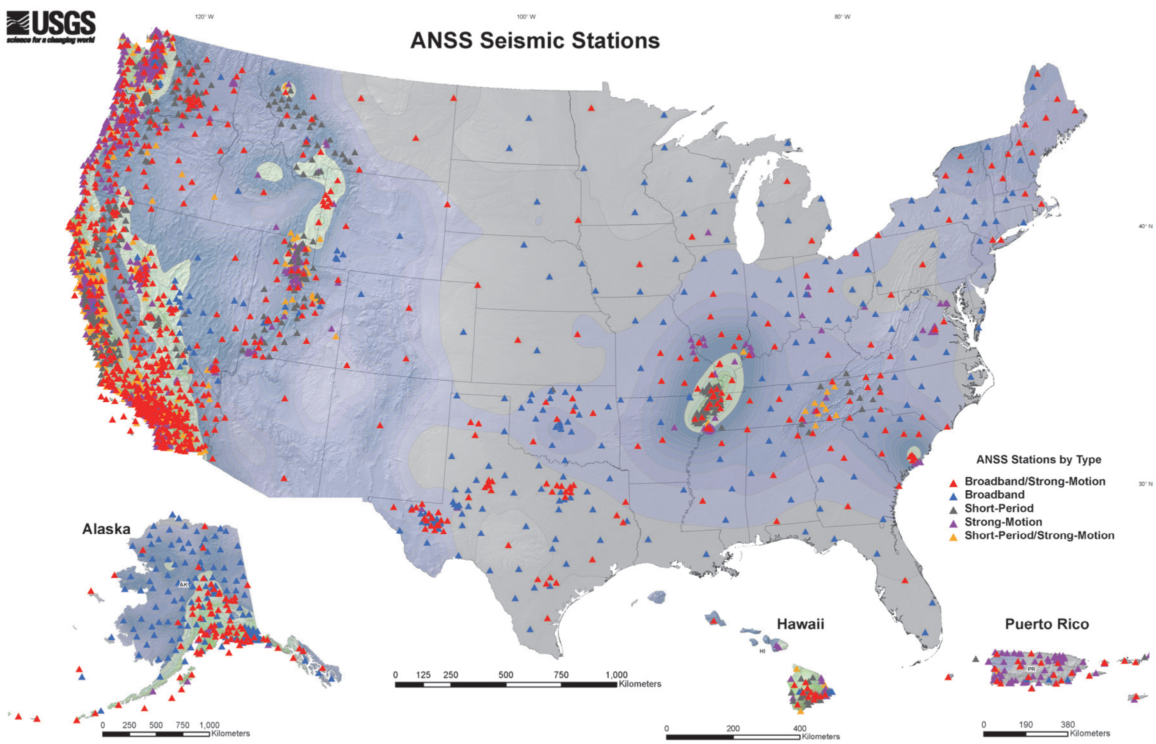


Figure 2-2. Map of ANSS free-field seismic stations across the United States in 2020, which are operated by national and regional seismic networks. Background shading illustrates higher hazard regions in the National Seismic Hazard Model, shading aligns with that shown in Figure 1-1. Notice the greater density of seismic stations in regions with either higher hazard, higher risk, or both. Image courtesy of Harley Benz, Gregory Smoczyk, and Eric Jones, USGS.

Objective 4 Advance the understanding of the consequences of earthquakes and associated hazards to society and the built environment.

Observations from recent and historic earthquakes play a critical role in developing our knowledge of their consequences. Significant physical damages, economic losses, injuries and deaths, and societal impacts from service interruptions can be caused by earthquakes, even moderate ones (see Figure 2-3). Earthquake risk depends on the expected intensity and rate of occurrence of seismic shaking (hazard) and the potential societal and economic consequences.

Since earthquakes are not preventable, NEHRP research efforts aim to better understand risks and reduce their consequences. Fundamental to this objective is research to understand the factors that contribute to earthquake consequences, comprehend factors that make the built environment vulnerable to earthquakes, ways to mitigate those vulnerabilities, and factors that either promote or inhibit adoption of different mitigation measures.

It is also important to understand the impact of cascading consequences from coincidental and/or sequential hazards, and the societal responses to them. Coincidental hazards are multiple unrelated or loosely related hazards that occur within the same disaster, response, and recovery period. For example, extreme rainfall or a pandemic occurring simultaneously with an earthquake present coincidental hazards to a community. Sequential hazards are multiple hazards that are directly related to each other and which occur within the same disaster, response, and recovery period. For example, a levee fails because of an earthquake, flooding a downstream community, or an earthquake causing a tsunami would be sequential hazards.

In addition to the consequences from multiple hazards on response and recovery, it is important to understand the consequences of implementing design and construction practices targeted toward a desired performance under other hazards. This includes the design implications for hazardous events that may occur infrequently.

Figure 2-3. Photo of people gathering on Freedom Plaza in Washington, D.C., after the M5.8 Mineral, VA earthquake on August 23, 2011. The epicenter of the earthquake was nearly 100 miles away from Washington, DC. Business operations were effectively interrupted for the rest of the day as assessments for damages were conducted. Photo credit: Mandel Ngan/AFP/Getty Images.

Outcome: Improved knowledge of the consequences of an earthquake on society and the built environment will support development of tools and practices to mitigate seismic risks. Efforts will lead to improved understanding and estimates of the impact from cascading hazards over various geographic scales, time periods, and geologic settings.

Objective 5 Advance the understanding of social, behavioral, and economic factors, including equity, pertinent to implementation of earthquake preparedness, mitigation, and recovery strategies.

Seismic risk reduction is only possible if preparations are made, vulnerabilities are reduced, and recovery processes are carefully considered and planned. Appreciation and adoption of necessary strategies depends on social, behavioral, and economic factors, including equity. Actions must be informed by the understanding of the disproportionate impacts that vulnerable construction material and practices can have on underserved communities. Research that integrates engineering with social, behavioral, public policy, and economic sciences in an equitable manner is thus of critical importance. This includes studies focused on risk perceptions and tradeoffs, mitigation incentives for households and communities, risk communication, and roles that private and public sectors could play to help reduce earthquake losses, including issues related to federal, state, and local financial mechanisms, such as disaster relief policies and the availability and affordability of earthquake insurance. Research on the content, accuracy, and accessibility of earthquake preparedness and response information is fundamental to supporting this objective.

Outcome: Improved understanding of social, behavioral, public policy, and economic factors driving risk reduction measures and improved recovery planning and practices.

Goal 2: Enhance existing and develop new information, tools, and practices for protecting the nation from earthquake consequences.

NEHRP will build upon results from Program activities within Goal 1 to support targeted fundamental and applied disciplinary and interdisciplinary research that enhances existing and designs new technologies, practices, procedures, tools, and standards. Outcomes of this research should impact mitigation practices that can reduce earthquake consequences on society, the economy, and the built environment. In this context, the built environment includes physical infrastructure and critical services that rely on it (e.g., facilities critical to public health, business continuity, key economic or governmental functions, and utilities production and distribution networks). Products of Program activities that support this goal will include, but are not limited to:

- more accurate and efficient risk assessment methodologies and loss estimation tools with relevant output to facilitate scientifically supported decision making by stakeholders;
- new earthquake-resistant, cost-effective engineering analysis, design, and construction techniques;
- new and innovative materials and systems for efficient construction and retrofit;
- revised guidance materials suitable for use in the seismic safety elements of model building

code promulgated by standards development organizations;

- the scientific understanding needed to support development and implementation of earthquake early warning along the west coast of the United States; and
- improved knowledge of earthquake resilience and tools to measure successful implementation.

The fundamental outcomes of Goal 2 are solutions focused on risk assessment and mitigation strategies to support earthquake preparedness. Goal 2 forms the basis for implementation efforts by the Program in Goal 3 to ensure that products are widely distributed in easily accessed formats.

Objective 6 Enhance current earthquake scenarios, risk assessment methodologies, and loss estimation tools to improve seismic risk information.

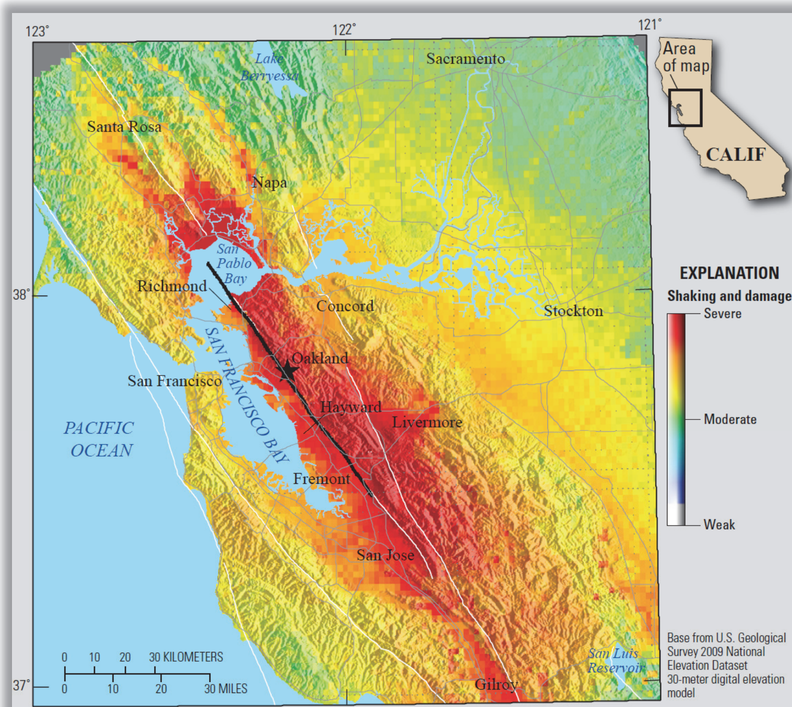
Earthquake scenario studies are effective mechanisms for sharing integrated information about potential ground motion surface intensity and distribution of potential impacts. Earthquake scenarios employ simulation, risk, and loss-estimation tools and highlight potential vulnerabilities within a community or region, pointing to key mitigation strategies required to reduce those vulnerabilities and highlighting needed post-earthquake response and recovery measures. Figure 2-4 is drawn from the 2018 HayWired Earthquake Scenario that described the expected impacts of a M7.0 earthquake on the Hayward Fault in the San Francisco Bay area. It depicts the expected distribution of peak ground motions and damage.

Identified vulnerabilities could include classes of vulnerable building systems or components, such as unreinforced masonry structural walls, or especially important vulnerable entities, such as essential facilities or lifeline infrastructure components. To be most effective, community leaders, representing both government and private interests, should be involved in funding, designing, and developing these scenarios, ensuring that results are accepted and actionable.

Beyond scenario studies, other loss estimation and risk assessment tools can be employed to support development and enhancement of federal, state, and local emergency management and response policies for the post-earthquake environment. For example, identifying best practices for assessing risk, along with community adoption of model building codes, using FEMA's HAZUS-MH[9] to identify areas with high risk from earthquakes to estimate physical, economic, and social impacts from earthquakes and support development of mitigation, preparedness, recovery, and response strategies.

Outcome: Application of scenario studies and other earthquake loss and risk modeling tools to improve the understanding of specific earthquake risks and vulnerabilities will help support the adoption of effective and efficient mitigation and emergency response, relief, and recovery planning and practices.

[9] https://toolkit.climate.gov/tool/hazus



This map of the San Francisco Bay region, California, shows simulated ground shaking caused by the hypothetical magnitude-7.0 mainshock of the HayWired earthquake scenario on the Hayward Fault. Red shows the most extreme ground shaking and where damage is the worst. The mainshock begins beneath the City of Oakland (star) and causes the Hayward Fault to rupture along about 52 miles of its length (thick black line). White lines are other major faults in the region.

Figure 2-4. HayWired Earthquake Scenario Seismic Hazard Map. Figure from *The HayWired Earthquake Scenario, We Can Outsmart Disaster* (USGS 2018).

Objective 7 Further develop and implement a West Coast earthquake early warning system and its associated communication, education, and outreach.

Earthquake early warning (EEW) capabilities are in the process of being implemented and have rolled out to the public in California, Oregon, and Washington[10]. Such systems can detect an earthquake in progress and may provide notice up to seconds to tens of seconds prior to actual ground shaking, see Figure 2-5. Depending on a user's distance from the earthquake, alerts may be delivered before, during, or after the arrival of strong shaking. The purpose of the system is to reduce the impact of earthquakes and save lives by providing alerts that are transmitted to the public via mass notification technologies and through more detailed data streams to institutional users and commercial service providers, who in turn may trigger automated user-specific actions. Potential applications include safely stopping elevators,

[10] USGS (2018). *Revised Technical Implementation Plan for the ShakeAlert System—An Earthquake Early Warning System for the West Coast of the United States.*

halting trains, monitoring critical systems, and alerting people to take protective actions such as drop, cover, and hold on.

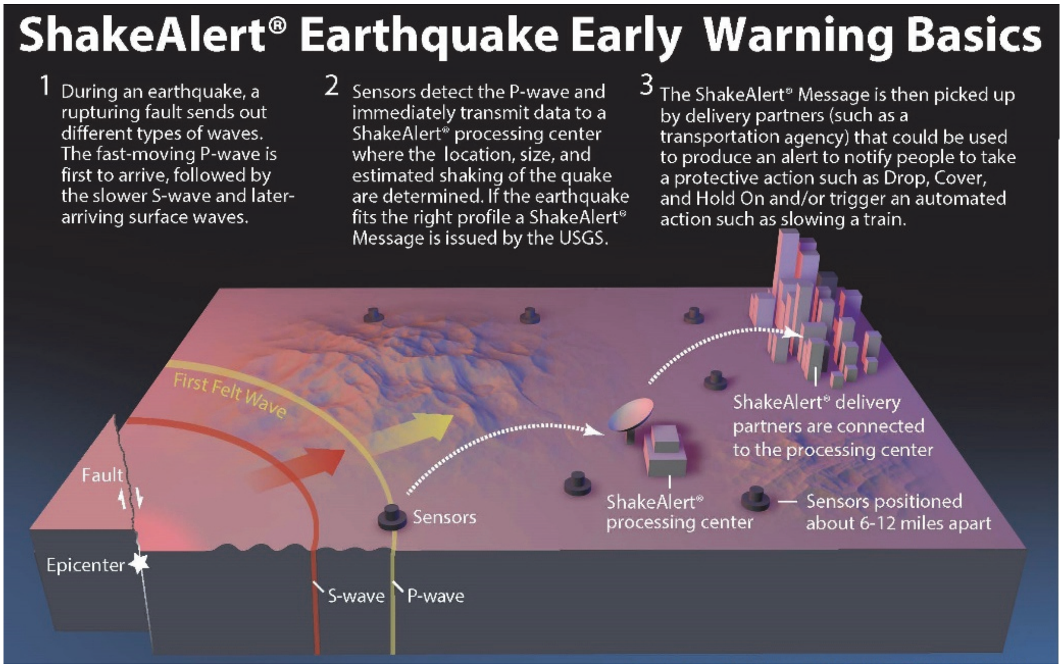


Figure 2-5. Earthquake early warning systems like ShakeAlert work because the warning message can be transmitted almost instantaneously, while shaking waves from the earthquake travel through the Earth at speeds of a few miles per second. Computers and mobile phones receiving the alert message can calculate the expected arrival time and intensity of shaking at your location. USGS image created by Erin Burkett (USGS) and Jeff Goertzen (Orange County Register).

The efficacy of the EEW system is predicated on the health of the monitoring networks providing the real-time data (see Goal 1, Objective 3). Additionally, efforts to provide essential education and outreach regarding the system's tangible capabilities must accompany system roll outs.

Outcome: A robust and reliable EEW system that is integrated into everyday life on the West Coast. Data collection will also inform assessments of the viability of an EEW system for other parts of the nation.

Objective 8 Enhance and develop cost-effective tools and practices, including up-to-date building codes and national consensus standards, that improve the seismic performance of new and existing buildings and lifeline infrastructure.

The seismic performance of the built environment is a key contributor to a community's ability to mitigate, respond to, and recover from a future earthquake. Components of the built environment are generally classified as *ordinary*, *high occupancy*, or *essential* (or *critical*) based on the level of risk they pose to the community if they were to fail during an earthquake. However, the targeted seismic performance for a given earthquake intensity in design is not always consistent across all components. For example, the targeted seismic performance of a bridge is not the same as that for a hospital.

Targeted fundamental and applied research and problem-focused studies into earthquake-resilient and -resistant design and construction techniques are essential for development of tools, technologies, codes, standards and other measures to improve seismic performance of new and existing buildings and lifeline infrastructure (see Figure 2-6).

Figure 2-6. Seismic response test of a deep, slender wide-flange structural steel column at the University of California, San Diego (UCSD) with the CALTRANS Seismic Response Modification Device. The columns are commonly used in steel-frame buildings. This research project was a collaboration between NIST, American Institute of Steel Construction, Applied Technology Council, and UCSD. Photo courtesy of C.-M. Uang at UCSD.

New or enhanced design and construction practices are not just focused on physical structures; they include criteria decision makers can use when deciding what practices to adopt. For example, more decision makers are considering if and how new and existing buildings and lifeline infrastructure can be designed and built for "functional recovery" after earthquakes, not just for life safety. Functional recovery as a design goal demands new, more varied and complex analysis and design approaches. It presents new problems that researchers will need to solve, and new design approaches engineers will need to learn to implement. In addition, to achieve maximal uptake of any sort of seismic performance measures, research must also address cost-benefit considerations since economics matter significantly in decisions about mitigation investments.

Building codes and standards are critical mechanisms to implement and disseminate the latest earthquake resistant design and construction techniques and practices, see Goal 3, Objective 12. These documents must be continually updated to reflect the best available earthquake science and engineering advancements to effectively support public policies for seismic safety.

Of importance related to the research to support the resilience of the built environment are the NSF-supported earthquake engineering experimental facilities and centers. One example is the Natural Hazards Engineering Research Infrastructure[11] (NHERI), which is a successor of the George E. Brown, Jr. Network for Earthquake Engineering Simulation. NHERI provides shared-use infrastructure for conducting geotechnical and structural earthquake engineering research (see Figure 2-7) as well as research relevant to other natural hazards. NHERI enables researchers from all sorts of institutions to have access to major research infrastructure to conduct innovative investigations with implications for mitigating damage from natural hazards.

Outcome: Improvements to engineering design and construction practices for new and existing buildings and lifeline infrastructure. Adoption of improvements by code and standards bodies, building designers, regulators, and the construction industry. Rapid translation of research findings to decision support for building owners and to the building codes and standards development process ultimately will lead to improved earthquake safety policies and mitigation strategies.

Objective 9 Advance knowledge to facilitate characterization of earthquake resilience and develop tools to measure successful implementation of resilience practices and policies.

There has been a major effort in recent years to quantitatively define earthquake resilience and the time it can take after an earthquake to recover to a pre-event measure. Progress in this area will support development of implementable frameworks for community resilience. *The Community Resilience Planning Guide* (NIST 2016), *National Disaster Recovery Framework* (FEMA 2011), and efforts by the U.S. Resiliency Council provide targeted information to support community resilience. Like codes and standards, these can be updated when improved measures and analytical tools are developed.

[11] https://www.designsafe-ci.org/about/

Figure 2-7. Key organizations in NHERI; includes coordination office, experimental facilities and capabilities, high-performance computing capabilities, and other support components. Image courtesy of Purdue University.

Another critical need in characterizing earthquake resilience is the development of tools that can appropriately measure the change in a community's resiliency based on pre-earthquake mitigation efforts, post-event repair or improvements, availability of construction resources, and economic impacts (see Figure 2-8). A related aspect of recovery that needs to be addressed is that the restored conditions may not be identical to pre-disaster conditions. Tools to support community decisions about desirable vs. achievable recovery states can have far-reaching implications as earthquake resilience becomes a primary mechanism for condition assessment of the built environment.

Outcome: Development of improved measures of earthquake resilience, including measures of expected improvements in resilience given mitigation activities or investments, will help stakeholders adopt more informed and effective practices and policies.

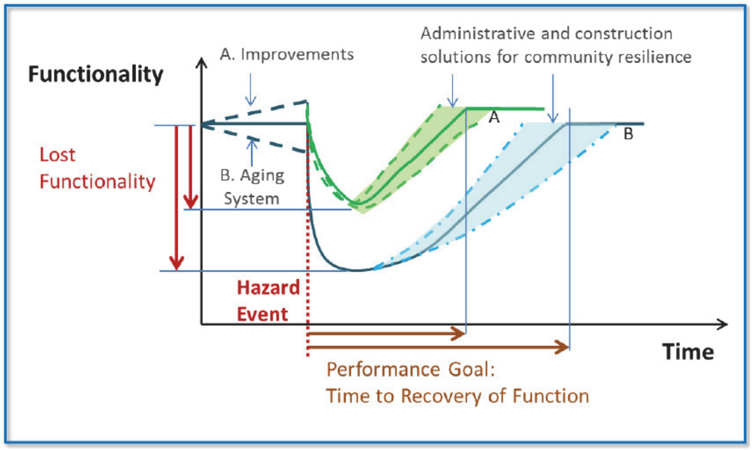


Figure 2-8. Resilience can be expressed in terms of system functionality and the time to recover functionality following a disruptive hazard event. Figure from *Community Resilience Planning Guide for Buildings and Infrastructure Systems*, Volume I: *Introduction* (NIST 2016).

Goal 3: Promote the dissemination of knowledge and implementation of tools, practices, and policies that enhance strategies to withstand, respond to, and recover from earthquakes.

NEHRP will promote the implementation and adoption of efficient and effective earthquake safety practices and policies at all levels of government, within the private sector, and by the public in general. Program activities that support this goal will include, but are not limited to:

- dissemination of rapid and accurate results from data analysis provided by ANSS and GSN on potential earthquake impacts to emergency responders and affected communities;
- dissemination of modeling and scenario tools to illustrate and forecast earthquake shaking patterns, seismic hazard maps, and potential impacts on the built environment;
- participate in the development of model building codes and design and construction standards and guidelines relevant to earthquake safety, and support their implementation through the adoption of seismic safety elements in codes, standards, policies, and practices;
- support state, local, tribal, and territorial hazard mitigation efforts, ordinances, programs, and incentives; and
- support training, outreach, and education efforts for state, local, tribal, and territorial leaders, the private sector, and the public.

This goal commits the Program to working to ensure that information and tools are designed in ways that are useful to stakeholders and to support the implementation of effective earthquake preparedness and risk reduction practices and policies. The fundamental outcome of Goal 3 is promotion of knowledge and tools to enhance preparedness and risk communication strategies that improve the nation's ability to withstand, respond to, and recover from earthquakes. Goal 3 forms the basis for evaluation efforts by the Program in Goal 4.

Objective 10 Enhance the accuracy, timeliness, usefulness, and accessibility of earthquake information products for a diverse range of users to better prepare for and respond to earthquakes.

Response to an earthquake requires real-time data gathered from ANSS and GSN (see Goal 1, Objective 3). This data must also be processed in real-time so that the information released to users is accurate and useful to support their needs in response and recovery efforts. Two examples of real-time processed information for users are ShakeMap and Prompt Assessment of Global Earthquakes for Response (PAGER). ShakeMap, produced and distributed within minutes of an earthquake, provides a quantitative graphic depiction of the measured and estimated severity and distribution of ground shaking in an impacted area. PAGER couples ShakeMap with data on population density and infrastructure fragility to provide rapid estimates of fatalities and economic losses (see Figure 2-9).

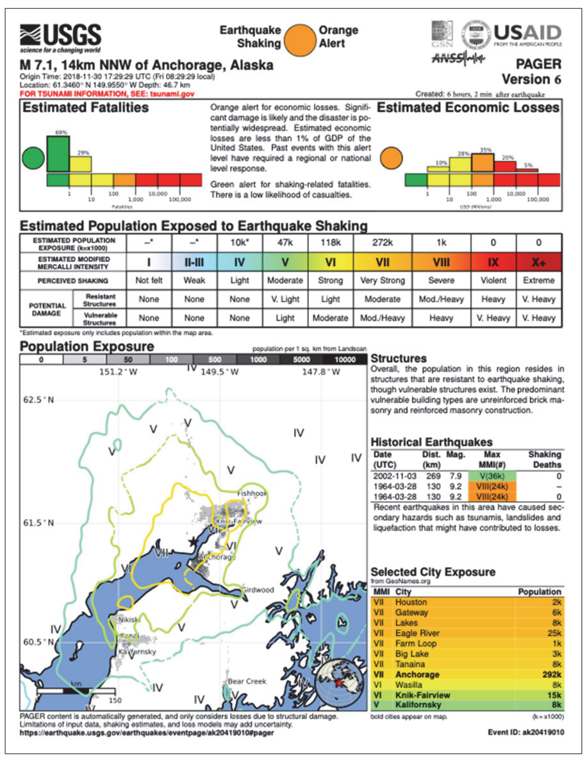


Figure 2-9. PAGER summary of loss estimates for the M7.1 November 30, 2018 Anchorage, Alaska earthquake. The earthquake impact scale alert level is indicated at the top of the page (orange alert), which is the higher of the economic loss alert (orange) and the fatality alert (green). The map summarizes shaking intensity with contours, and gives the population density, which is a visual summary of the information that the loss calculations are based on. Image courtesy of USGS.

These products provide vital quantitative projections of an earthquake's impact for emergency response officials and the public. Managers of lifeline infrastructure, medical facilities, and business interests can also use ShakeMap and ShakeCast, an associated product, to estimate damage to specific facilities and services. Because the accuracy of ShakeMap depends on the number and distribution of seismic instruments providing data for analysis, the successful realization of ShakeMap capabilities is directly linked to ANSS capabilities. Data can be used after the primary stages of response have ended to update local policies for preparedness strategies for a future earthquake.

Outcome: A standardized, comprehensive, and modern seismic monitoring and data analysis system, providing high-quality data and information for accurate and timely notification on earthquakes and their impacts to users. Products will support mitigation and preparedness measures and emergency response capabilities as well as essential data for tsunami warning, earthquake hazard and loss assessments, and to support basic and applied research in seismology and engineering.

Objective 11 Implement and regularly update a National Seismic Hazard Model based on the latest research, source models, seismicity, and field studies, essential for implementing state-of-the-art mitigation, design, and construction strategies.

The National Seismic Hazard Model (NSHM) forecasts earthquake ground motions across the nation and integrates information on where and how often earthquakes are likely to occur, the range of magnitudes of those earthquakes, and how strongly they may shake the ground. The NSHM is updated every several years to incorporate the latest earthquake science, see Objectives 1, 2, and 3 in Goal 1. A critical output of the NSHM is the National Seismic Hazard Maps or their derivatives as shown for example in Figure 2-10.

These maps portray ground shaking information to help engineers and other users to determine the required robustness of the built environment for an area. The hazard model, and a variety of maps and engineering tools derived from it, are regularly updated to incorporate the most accurate and up-to-date information about potentially damaging earthquakes throughout the nation. The hazard model and maps are also used by many federal, state, and local private and community users, for example:

- to form the basis for earthquake safety provisions in model building codes, such as the International Codes, by quantifying the hazard levels selected by the code for seismic design or assessment of the built environment;
- as the basis for seismic risk and loss assessment products by FEMA;
- in the Tri-Service building code developed by the Department of Defense;
- in the bridge code developed by the American Association of State Highway and Transportation Officials;

- in the railway code developed by the American Railway and Maintenance-of-way Association;
- in dam safety measures maintained by the U.S. Army Corps of Engineers and by the U.S. Bureau of Reclamation;
- in safety measures for federal buildings maintained by the General Services Administration;
- in landfill safety specifications of the Environmental Protection Agency;
- by the insurance industry to set premium levels for earthquake insurance and reinsurance policies;
- in construction codes for gas, water, and sewage pipelines; and
- by a variety of state and local agencies to determine zoning for landslide and liquefaction hazard and to evaluate the seismic safety of schools.

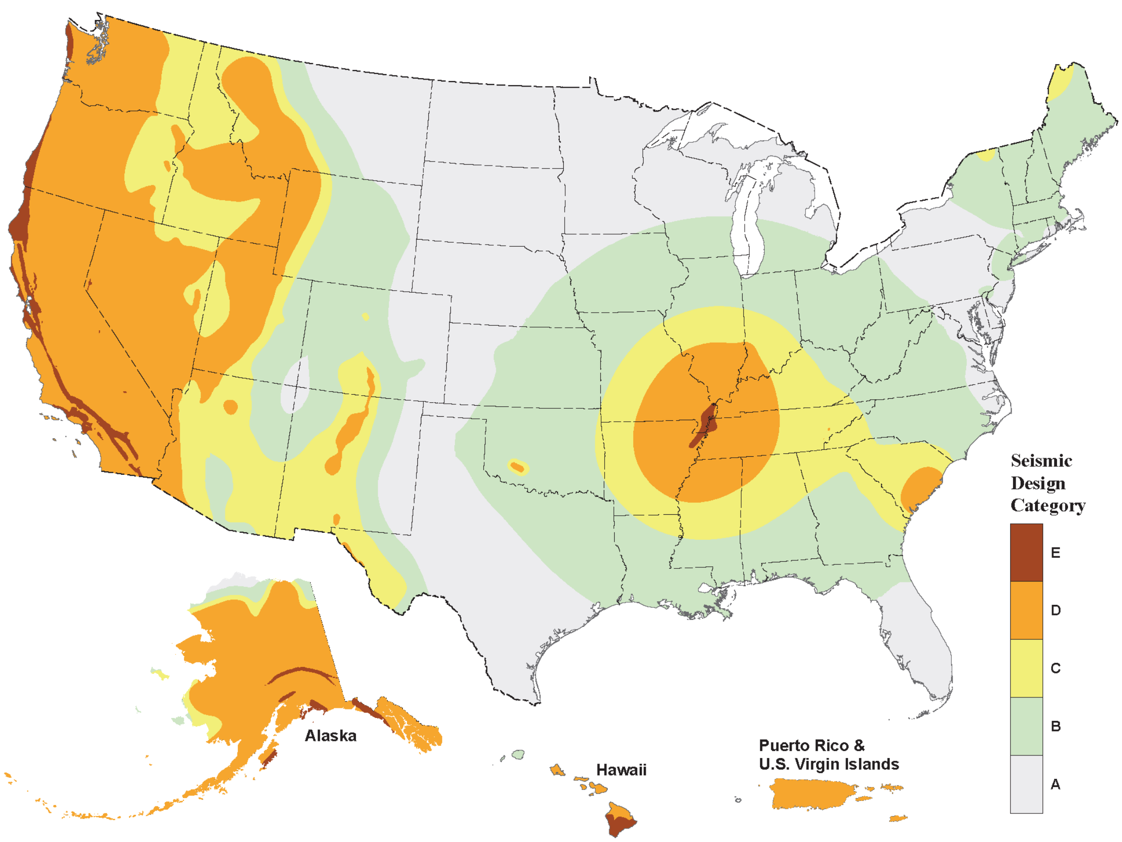


Figure 2-10. Seismic Design Categories (SDCs) for default site conditions in the continental United States, Hawaii, Puerto Rico, and U.S. Virgin Islands based on the 2018 USGS National Seismic Hazard Model and procedures in the 2020 NEHRP Recommended Seismic Provisions for New Buildings and Other Structures for design ground motion calculations. Image courtesy of Ken Rukstales, Sanaz Rezaeian, and Nico Luco, USGS.

Outcome: State-of-the-art seismic hazard data, assessments, forecasts, and tools that support developments and applications which underpin the state-of-the-practice for effective and efficient mitigation strategies and emergency response, relief, and recovery measures.

Objective 12 Actively engage in the continual development and use of up-to-date seismic design guidelines, standards and building codes, and advocate for their adoption and enforcement at the state, local, tribal, and territorial level.

Effective seismic risk reduction policies and practices are based on vetted outcomes from targeted fundamental and applied research and problem-focused studies, see Goal 2, as well as post-earthquake investigations in Goal 4. Knowledge generated from such efforts must be suitable for implementation into building codes and consensus standards to have the biggest impact throughout the nation. For measurable impact, successful action and implementation requires advocating for the adoption and enforcement of scientifically-supported seismic-resistant design and construction provisions in model building codes and national and industry consensus standards for new and existing buildings, non-building structures, and lifeline infrastructure. These codes and standards provide engineering provisions and guidelines that can be adopted in state, local, tribal, and territorial building code statutes to form jurisdictional design and construction policies. One such mechanism to advance building codes and standards is the *NEHRP Recommended Provisions for New Buildings and Other Structures* (most recently FEMA P-2082), see Figure 2-11.

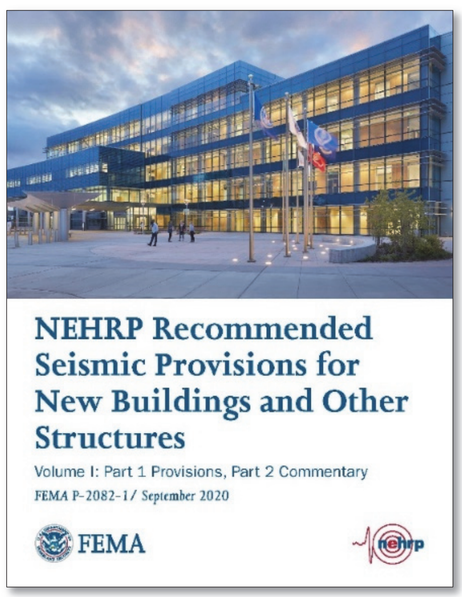


Figure 2-11. FEMA P-2082 (2020) *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures.*

Outcome: Improved, cost-effective earthquake safety through widespread adoption of the seismic design and construction provisions of building codes, standards, and guidelines that are based on realistic hazard assessments, current results of engineering research and testing, and systematic review and evaluation by professional organizations.

Objective 13 Support and enhance earthquake education, emergency drills, and exercises to promote effective earthquake awareness as well as mitigation, response, and recovery planning.

Seismic safety depends not only on up-to-date building codes, standards, and guidelines but also on a community's seismic safety culture. Education efforts (see Figure 2-12) can promote, for example:

- awareness by the public and policy makers about earthquakes and their consequences;
- preparedness actions that can be taken before an earthquake occurs;
- what actions to take during an earthquake;
- explanations of how adopted codes and standards matter to a community's resilience;
- planning guidance to assist response and recovery efforts; and
- information about the support services available to the public before and after an earthquake.

Emergency drills and exercises at the community, regional, and national level are valuable tools to reinforce the education objective and provide mechanisms for practicing necessary actions to enhance preparedness, decrease response and recovery time, and communicate critical information to the public.

Figure 2-12. Grade schoolers learn about earthquakes during a visit to the National Earthquake Information Center. Photo courtesy of USGS.

An emergency drill and earthquake scenario, see Goal 2, are not equivalent activities, but can be used in tandem to develop a broadly scoped exercise to evaluate emergency response actions for a given consequence, evacuation plans and routes, and needed short and long-term supplies. The Great Southern California ShakeOut Scenario in 2008 is an example of such a synergetic combination. The scenario was used to develop the Great ShakeOut[12], which has since become an international-level earthquake emergency drill held every third Thursday of October. The Great ShakeOut drill is an opportunity for the public to practice how to be safer during earthquakes. It is also used to encourage community policy makers, organizations, and the public to develop, enhance, or update their emergency plans and supplies, and to make their communities more earthquake-safe in order to help prevent damage and injuries.

Outcome: Increased effectiveness of earthquake awareness and safety through the development and promotion of consistent and constructive tools and exercises to educate the public and to support the testing of risk mitigation policies and practices.

Objective 14 Promote the implementation of earthquake preparedness, safety, response, and recovery strategies, which account for social, behavioral, and economic factors, including equity.

Implementation begins with public awareness of hazards and options for reducing risks. NEHRP efforts must support access to information that may assist the public and public officials in preparing for, responding to, and recovering from earthquakes.

A variety of mechanisms can be employed to reach appropriate audiences, including websites, publications, and presentations for professional, trade, and public interest groups; dissemination of information materials at public forums and conferences; workshops, cooperative efforts with other federal, state, local, tribal, and territorial partners; and communications initiatives to increase public awareness of earthquake risk and measures that can be undertaken to reduce or eliminate its effects. For example, Figure 2-13 shows information booths at a national earthquake engineering conference; booths commonly contain recent publications.

In addition, NEHRP promotes the implementation of needed safety guidance and training by fostering collaborations amongst NEHRP partners. For example, FEMA funds the administration of the National Earthquake Technical Assistance Program[13] (NETAP) to help state, local, tribal, and territorial governments obtain the knowledge, tools, and support that they need to plan and implement effective earthquake mitigation strategies and QuakeSmart[14], a program that guides businesses and organizations of all sizes to identify potential

[12] https://www.shakeout.org
[13] https://www.fema.gov/emergency-managers/risk-management/earthquake/training/netap
[14] https://www.fema.gov/emergency-managers/risk-management/earthquake/training/quakesmart

vulnerabilities and learn ways to reduce earthquake-related losses.

Figure 2-13. Program information booths for FEMA and NIST at a national earthquake engineering conference. Sometimes an information booth is jointly staffed. Photo courtesy of NIST.

Workshops are a valuable mechanism to foster awareness and action by the earthquake science and engineering community. In addition to earthquakes, workshops can be supported to focus on implementing knowledge gained by lessons learned from the COVID-19 pandemic, other natural or man-made hazards, climate change, and data-driven models and new sensing technologies.

Outcome: Increased public understanding of earthquake safety issues, including interpretation of earthquake forecast statements. Improved technology and knowledge transfer will enable appropriate earthquake professionals and the public to adopt cost-effective knowledge and tools, reducing overall earthquake vulnerabilities for the nation.

Goal 4: Learn from post-earthquake investigations to enhance the effectiveness of available information, tools, practices, and policies to improve earthquake resilience.

NEHRP has the responsibility to gauge the effectiveness of information, tools, and practices regarding improving earthquake resilience of the nation. Real-world lessons from domestic and, sometimes, international earthquakes offer especially important insights about what works and what does not. NEHRP is committed to ensuring the important lessons are learned from significant events and how structures within those events performed.

For example, lessons from the 1964 Great Alaska earthquake led to changes in codes and standards in Anchorage; studies following the 2018 Anchorage earthquake concluded that several of those changes had been effective in preventing disproportionate damage to the built environment. Another example of how important resilience lessons can be learned is by examining the Torre O'Higgins building in Concepción, Chile during the ten-year period after it was catastrophically damaged in the M8.8 2010 Maule, Chile Earthquake (see Figure 2-14). Ten years after the earthquake, the re-configured building is once again a functioning component of the community.

(a) (b)

Figure 2-14. Torre O'Higgins building in Concepción, Chile: (a) building as damaged in the 2010 Maule, Chile Earthquake (photo courtesy of J. Harris) and (b) operational condition of the building ten years after the earthquake, parts of the originally constructed building were deconstructed (photo credit: Reid Middleton).

Post-earthquake analyses by NEHRP and its partners of earthquake consequences, their root cause, the risks they pose to the nation, and promotion of successful mitigation strategies against future earthquakes may take years, even decades, and is dependent on available resources. In terms of the flow of the strategy defined in this Plan, it is intended that findings and data supported under Goal 4 provide the basis for activities related to Goals 1, 2, and 3, ensuring continual improvement in Program products and actions.

Objective 15 Maintain and advance program-wide procedures and policies for post-earthquake investigations and data acquisition management.

Any effort to conduct a comprehensive post-earthquake investigation and data acquisition operation must be supported by a well-conceived plan that outlines the roles and responsibilities of all parties present and the initial timeline of actions. USGS Circular 1242:

The Plan to Coordinate NEHRP Post-Earthquake Investigations (USGS 2003) is the current plan to coordinate domestic and foreign post-earthquake investigations conducted by and/or supported by NEHRP agencies, see Figure 2-15.

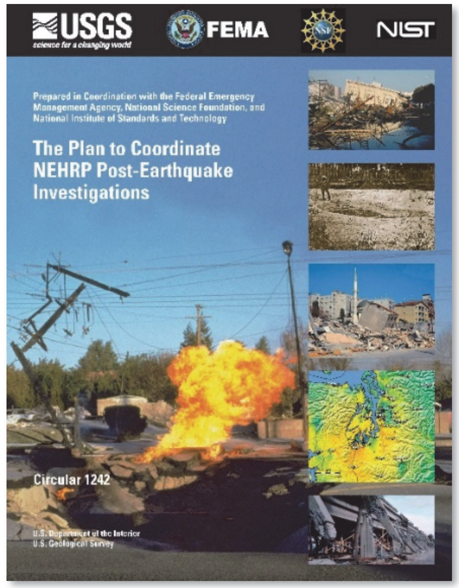


Figure 2-15. USGS Circular 1242 (2003): *The Plan to Coordinate NEHRP Post-Earthquake Investigations*. A project is currently ongoing to update this document.

The plan is a framework for both coordinating what is going to be done and identifying responsibilities for post-earthquake investigations that may occur immediately after an earthquake to decades later. The plan includes measures for (1) gaining rapid and general agreement on high-priority research opportunities and (2) conducting the data gathering and field studies in a coordinated manner. It deals with identification, collection, processing, documentation, archiving, and dissemination of the results of post-earthquake work in a timely manner and easily accessible format. This plan must be periodically updated based on new knowledge gained from lessons learned identified during post-earthquake investigations.

Outcome: An updated post-earthquake investigations coordination plan for NEHRP and its partners to guide how important data are collected, analyzed, shared, and archived in order to advance the program's goal of improving earthquake resilience and risk reduction. The plan identifies agency roles and responsibilities, key partners and stakeholder groups, and high-priority investigation goals. It also identifies potential ways in which the program agencies might enhance the impact of post-earthquake investigations though expanded activities, processes and policies that would build upon current practice.

Objective 16 Advance earthquake preparedness, safety, response, and recovery strategies by translating post-earthquake investigation results into approaches for improved resilience.

Documenting and sharing lessons learned across many technical disciplines after a major earthquake is essential to supporting the readiness of the nation for the next earthquake. It may take time to translate lessons learned from research and problem-focused studies of an earthquake into tools, guidance, and other products for adoption by communities. A comprehensive understanding of the time needed to recover and to gauge a level of resilience may require Program involvement and activities to continue many years after an event. Studies may be needed many years later to examine the impacts of modifications to procedures, policies, or tools adopted after the event. For example, three years after the 2018 Anchorage, Alaska earthquake, the Anchorage communities are evaluating various levels of code enforcement to adopt in some localities.

However, some studies may need to be expedited in order to impact repair and recovery. Figure 2-16 shows a FEMA report presenting lessons learned from the 2014 South Napa Earthquake in California. This study led to two supplemental Recovery Advisories: *Repair of Earthquake Damaged Masonry Chimneys* (FEMA P-1024-RA1, 2015) and *Earthquake Strengthening of Cripple Walls in Wood Frame Dwellings* (FEMA P-1024-RA2, 2019).

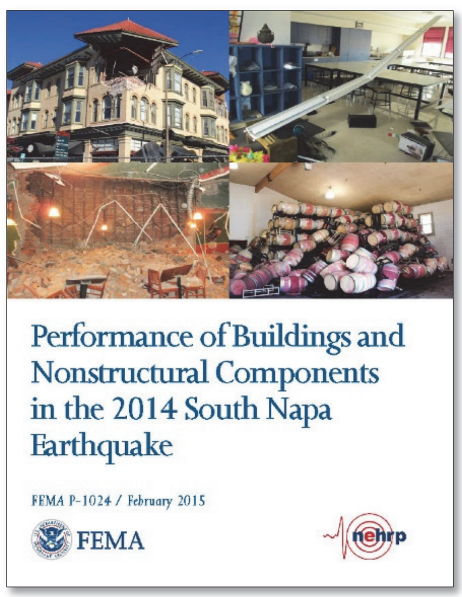


Figure 2-16. FEMA P-1024: *Performance of Buildings and Nonstructural Components in the 2014 South Napa Earthquake*. Image courtesy of FEMA. This study resulted in two Recovery Advisories: *Repair of Earthquake Damaged Masonry Chimneys* (RA1) and *Earthquake Strengthening of Cripple Walls in Wood Frame Dwellings* (RA2).

This objective also includes translating lessons learned from other disasters that could help increase earthquake resilience.

Outcome: Findings and data acquired during post-earthquake investigations are translated to improved codes, standards, and practices with potentially far-reaching impacts on the physical, social, economic, political, and cultural environments by advancing earthquake resilience.

Objective 17 Identify and take advantage of opportunities to collaborate on development of scientifically informed metrics and actions to evaluate community earthquake resilience after an earthquake, which account for social, behavioral, and economic factors, including equity.

To advance Objective 9 in Goal 2, collaborative post-earthquake research and investigation opportunities must be established to develop and advance quantitative metrics for assessing earthquake resilience of a community in an equitable manner. Collaborative activities must include a focus on the integration of:

- societal factors and needs;
- prioritized community interests and assets; and
- the performance of the built environment that serves the community.

Processes to derive lessons learned from these activities must engage community resilience stakeholders for input and feedback for planning and implementing resilience measures.

Outcome: Validated metrics for community earthquake resilience based on post-earthquake investigations.

Objective 18 Provide mechanisms to promote relevant feedback to the public regarding lessons learned from earthquakes.

Dissemination of lessons learned from a major earthquake to the public-at-large, policymakers, and architectural, engineering, and construction professionals is essential to support progress toward increasing earthquake resilience. There are many venues and mediums available for disseminating findings from post-earthquake studies and Goal 3 and its objectives provide mechanisms to share gained knowledge. For example, Figure 2-17 shows a meeting to share information and early lessons learned at the University of Alaska in Anchorage with NEHRP members and the structural engineering community a few months after the M7.1 2018 Anchorage, Alaska earthquake. Later that year, NEHRP supported a "one-year later" symposium in Anchorage that highlighted research efforts and findings over the prior year. The goal was to showcase a broad set of observations in a single symposium venue aimed to stimulate new investigations and collaborations to foster development of cross-disciplinary research agendas. Representatives of state and local interests and organizations attended to share their experiences and concerns and learn about research findings.

Figure 2-17. Meeting at the University of Alaska in January 2019 with members of the NIST earthquake reconnaissance team and the Anchorage, Alaska structural engineering community after the 2018 M7.1 Anchorage earthquake. Photo courtesy of M. Speicher.

Outcome: Provide relevant and easily understood lessons from earthquakes to earthquake professionals, policymakers, and the public.

Chapter

3

Program-Identified Focus Areas to Support NEHRP

The NEHRP agencies have identified eight focus areas that address important stakeholder needs and require increased emphasis by the Program agencies during the Plan period. Guiding principles for developing these focus areas are provided in Appendix C.

The focus areas reflect broader community needs and support general responsibilities as identified in the Earthquake Hazards Reduction Act of 1977, as amended, or relevant legislation and executive orders. These focus areas are as follows, not ranked in any order of priority:

1. Advance earthquake science for subduction zone regions.

   Subduction zones have produced the largest magnitude and longest duration earthquakes. These earthquakes can have devasting consequences in the Pacific Northwest and coastal Alaska as well as in U.S. territories in the Caribbean and Pacific Ocean Basin. There is a need to improve knowledge of subduction zone earthquakes, their causes, and their consequences, in addition to potential impacts over a broader geographical area due to tsunamis induced by this type of earthquake. Outcomes will allow the Program to implement improved hazard assessments, risk mitigation and communication strategies, and develop products for situational awareness for these regions.

2. Develop enhanced performance-based design procedures and metrics for the functional recovery of new and existing buildings and lifeline infrastructure.

   Earthquakes have consistently resulted in interruption of building operations and community-support functions (e.g., power distribution), as well as direct economic losses from damage to the operative contents and indirect economic losses by absence of provided services. Recovery time for buildings and lifeline infrastructure after an earthquake is67 directly impacted by the extent of damage, availability of financial and assessment resources, demolition and repair processes, and construction material availability. Recovery time is also tied to community-level indirect losses such as interruptions to the continuity of schooling, childcare, healthcare, and commerce. There is a need to continue to support the development and implementation of enhanced performance levels and associated performance-based seismic design guidance that explicitly address post-earthquake reoccupancy and reduced functional recovery time for buildings and lifeline infrastructure. Outcomes will allow the Program to support implementation of these enhanced levels to further minimize the consequences of an earthquake and their risks to society.

3. Advance performance-based seismic design and assessment methods to implement multi-system coordination.

Current performance-based seismic design efforts tend to focus on a single system (e.g., a building or power distribution network). There is a need to enhance performance-based seismic design and assessment methods to support integration across systems and sectors beyond prioritization by risk categorization. Efforts can support emerging community-level resilience-based design concepts. For example, developing a scientifically supported awareness of how the performance of one school after an earthquake may affect other schools with regards to the associated consequences for the school district. Allowing multiple systems to provide feedback to other potentially impacted systems during the design or assessment process will enhance risk assessments and associated decision metrics. Outcomes will allow the Program to implement guidance to support multi-system risk mitigation which can in turn support community-level resilience strategies.

4. Further expand earthquake early warning capabilities.

There is a need to continue efforts to support development and implementation of effective earthquake early warning (EEW) systems and actionable risk communication to the public, which can facilitate significant improvements in earthquake safety and reduced loss of life and injuries. Outcomes will allow the Program to assess the viability of EEW in other regions that have not already adopted EEW systems and include critical education and outreach to ensure that risk communication efforts are received by all sectors of the public.

5. Develop consistent performance guidance for lifeline infrastructure.

Lifeline infrastructure plays a key role in response and recovery efforts after an earthquake. Building codes and standards commonly focus on the design of single sector-based systems, and, as a result, many sectors have varying definitions of the seismic hazard used for design and the associated performance at these hazards levels. There is a need to advance the understanding of the performance of lifeline infrastructure during an earthquake as well as a need to improve monitoring and retrofit / repair strategies. Outcomes will allow the Program to develop and advocate for industry-based standards that support design consistency among lifeline infrastructure sectors. Lifeline infrastructure sectors include, but are not limited to, the following:

- Communications Sector;
- Manufacturing Sector;
- Energy and Gas Sector;
- Transportation Systems Sector; and
- Water and Wastewater Systems Sector.

6. Enhance guidance to ensure that information and tools effectively support the needs of those who implement mitigation, preparedness, and recovery measures.

Earthquake consequences on people within a community can result in loss of life, injury, and other long-term effects, which can include disability, displacement, loss of employment, educational disruption, and psychological impacts, among other examples. Earthquakes can also have disproportionate impacts on different populations. For example, people living in lower income neighborhoods may not have access to housing that is built or retrofitted with modern seismic safety measures. There is a need to advance social and behavioral research related to risk mitigation and recovery to support preparedness and community-resilience for future earthquakes. Outcomes will allow the Program to better align products with emerging community-level resilience needs and strategies to meet diverse needs including equity.

7. Advance the science of earthquake sequence characterization.

Earthquake sequences can last for months to years after, and at times begin sometime prior to, a defined mainshock. Extended earthquake sequences can be disconcerting to people responding to and recovering from a specific earthquake. There is a need to improve methods for describing sequences and forecasting the occurrence of aftershocks and earthquake swarms and their consequences on an impacted region. Outcomes will allow the Program to deploy operational forecast products that provide actionable information to support mitigation, response, and recovery strategies.

8. Enhance risk reduction strategies for federal agencies.

Executive Order (EO) 13717: *Establishing a Federal Earthquake Risk Management Standard* establishes minimum seismic requirements for new and existing buildings that will be constructed, altered, leased, financed, or regulated by the Federal Government. These requirements help enhance the seismic resilience of agencies by reducing risk to lives of building occupants and improving the probability of continued performance of buildings essential to agency operations and functions following future earthquakes. The Interagency Committee on Seismic Safety in Construction (ICSSC) was created as a function of NEHRP and is composed of representatives of all federal agencies engaged in construction, financing of construction, or related activities. The ICSSC mission is to assist federal agencies that are engaged in construction in developing and incorporating earthquake risk reduction measures in their ongoing programs. There is a need to advance efforts by the ICSSC to implement state-of-the-art guidance that promotes seismic risk reduction measures for all federal agencies. Outcomes will allow the Program, which oversees the ICSSC, to support federal efforts in risk reduction, allowing the federal agencies to lead by example in support of the EO.

Appendix

A

Abbreviations and Acronyms

ACEHR	Advisory Committee on Earthquake Hazards Reduction
ANSS	Advanced National Seismic System
EERI	Earthquake Engineering Research Institute
EHRA	Earthquake Hazards Reduction Act
EEW	Earthquake Early Warning
EO	Executive Order
FEMA	Federal Emergency Management Agency
FY	Fiscal Year
GSN	Global Seismographic Network
HAZUS-MH	Hazards U.S. Multi-Hazard (FEMA's Loss Estimation Methodology)
ICC	Interagency Coordinating Committee
ICSSC	Interagency Committee on Seismic Safety in Construction
IRIS	Incorporated Research Institutions for Seismology
M	Magnitude
NEHRP	National Earthquake Hazards Reduction Program
NEIC	USGS National Earthquake Information Center
NHERI	Natural Hazards Engineering Research Infrastructure
NIST	National Institute of Standards and Technology
NRC	National Research Council
NRF	National Response Framework
NSF	National Science Foundation
NSHM	National Seismic Hazard Model
NSTC	National Science and Technology Council
OMB	Office of Management and Budget
OSTP	Office of Science and Technology Policy
PAGER	Prompt Assessment of Global Earthquakes for Response
PBSD	Performance-based Seismic Design

PL	Public Law
PCWG	Program Coordination Working Group
SAGE	Seismological Facilities for the Advancement of Geoscience
SDR	Subcommittee on Disaster Reduction
SRST	Subcommittee for Resilience Science and Technology
USC	United States Code
USGS	U.S. Geological Survey

Appendix

B

NEHRP Today

Congressional Oversight and Mandates

Congress first authorized the National Earthquake Hazards Reduction Program (NEHRP) in 1977 in the Earthquake Hazards Reduction Act (EHRA) (42 U.S.C. § 7702). Congress oversees NEHRP in part through a periodic reauthorization process. The most recent reauthorization of the EHRA was Public Law 115-307 in December 2018, which authorized NEHRP funding through fiscal year 2022, and mandated management, oversight, and reporting requirements.

NEHRP Agency Statutory Responsibilities

By statute, the NEHRP agencies are:

- the Federal Emergency Management Agency (FEMA);
- the National Institute of Standards and Technology (NIST), the lead agency for NEHRP;
- the National Science Foundation (NSF); and
- the U.S. Geological Survey (USGS).

The agencies roles within the Program draw upon their mission strengths in a complementary and non-duplicative manner so that NEHRP effectiveness and efficiency are greater than would be accomplished by the agencies acting individually. Details on the roles and responsibilities can be found in the EHRA, see Appendix D. The Act does not identify emergency response responsibilities for the Program agencies. NEHRP does provide essential information and tools used in earthquake response, such as notifications of earthquake location and magnitude, estimates of the distribution and severity of ground shaking, and impact and loss assessments. In addition, FEMA is tasked by statute with executing the National Response Framework (NRF) as one of its core missions, and both NIST and USGS provide emergency support functions under the NRF that are not required under NEHRP.

Program Review, Oversight, and Administration

The planning, management, and coordination of NEHRP is overseen by the Interagency Coordinating Committee (ICC) on Earthquake Hazards Reduction, composed of the principals of the four Program agencies, the Office of Science and Technology Policy, and the Office of Management and Budget. The NIST Director chairs the ICC, which meets to coordinate agency policies and activities relevant to NEHRP, review progress, and address interagency issues that require resolution. As the Program lead agency, NIST staffs a NEHRP Office that supports the ICC. According to NEHRP legislation, the ICC is responsible for the following:

- a Strategic Plan (this document);
- a detailed Management Plan to implement the Strategic Plan;
- a coordinated interagency budget for the Program; and
- a biennial report.

The legislation specifies that the biennial report includes:

- a report on the Program budget for each NEHRP agency for the current fiscal year;
- a report on the proposed Program budget for each NEHRP agency in the next fiscal year;
- a description of Program activities and results for the previous year;
- a description of the extent to which the Program has incorporated the recommendations of the Advisory Committee on Earthquake Hazards Reduction (ACEHR); and
- a description of activities and associated budgets for the current and coming fiscal years for those Program agency activities that are not included in the Program but contribute to it.

At the working level, the Program is managed by the Program Coordination Working Group (PCWG), composed of representatives of the four NEHRP agencies and meets monthly to implement ICC policies and directives and coordinate NEHRP operational activities. The NEHRP Office at NIST supports the PCWG.

Program Advisory Committee

NEHRP is assessed by the Advisory Committee on Earthquake Hazards Reduction (ACEHR). According to NEHRP legislation, ACEHR is responsible for the following:

- assessing trends and developments in the science and engineering of earthquake risk reduction;
- assessing the effectiveness of the Program in carrying out its statutory activities;
- assessing the need to revise the Program; and
- assessing the management, coordination, implementation, and activities of the Program.

ACEHR balances representation from research and academic institutions, industry standards development organizations, state, local, tribal, and territorial governments, and financial communities who are qualified to give advice on earthquake hazards reduction. ACEHR, which is appointed by and reports to the NIST Director, is established under provisions of the Federal Advisory Committee Act (5 U.S.C. Chapter 10). The Designated Federal Official for ACEHR is located within the NEHRP Office at NIST and the NEHRP Office supports ACEHR activities. ACEHR is required to submit biennial reports of its assessments and recommendations for advancing NEHRP to the NIST

Director.

NEHRP Impact on the Built Environment

A major function of NEHRP is to act as a pre-disaster research, planning, and implementation body, although individual NEHRP agencies may have separate authorities, such as those under the National Response Framework and the Stafford Act. Much of what NEHRP performs is tied closely to design and construction practice in the United States.

Figure B-1 illustrates the role of NEHRP in impacting the built environment, a primary facet of Program activities. Although Figure B-1 does not represent all of what NEHRP accomplishes, it provides insight into a significant portion of NEHRP's activities. Figure B-1 illustrates how the activities of NEHRP agencies fit together and complement one another. Throughout this process, the four Program agencies interact with earthquake professionals in the private sector, in the national model building code organizations, in academia, and in state, local, tribal, and territorial government.

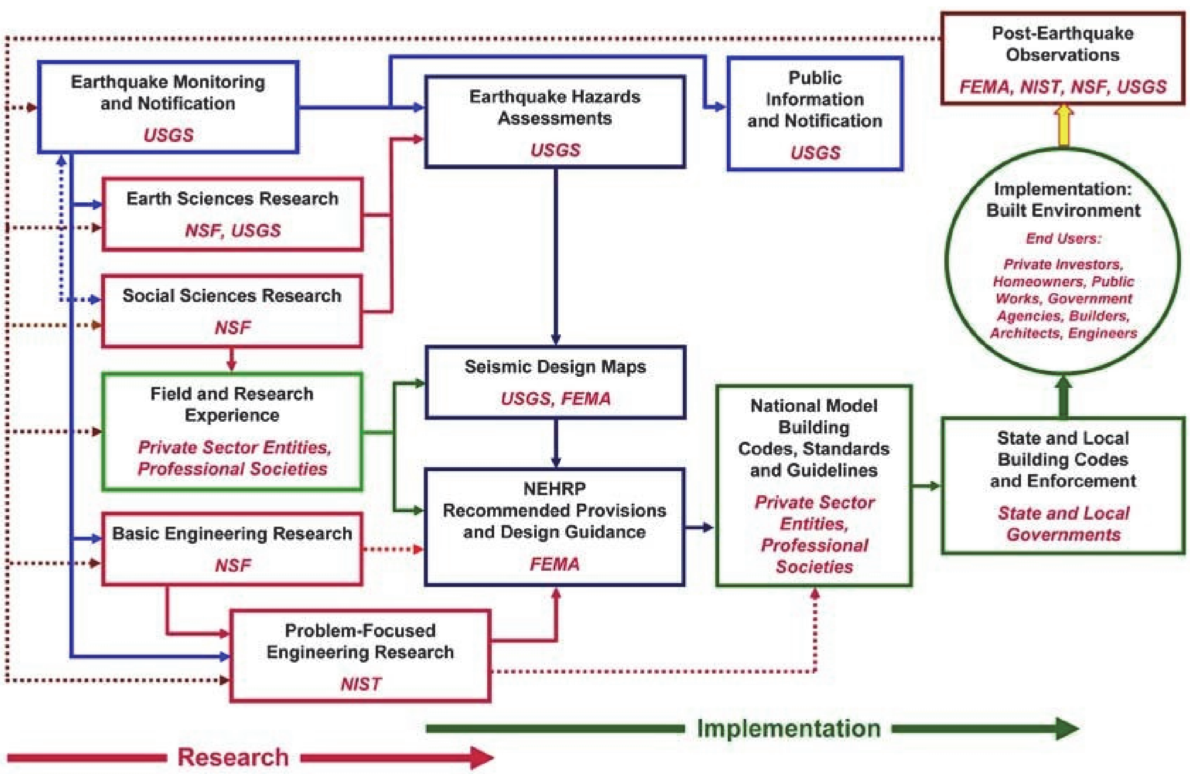


Figure B-1. NEHRP Impact on Building Design and Construction. Image courtesy of NIST.

Using the resources of the Advanced National Seismic System (ANSS) and the Global Seismographic Network (GSN), USGS monitors earthquake activity to notify those in affected areas and collect data to develop earthquake hazards assessments, which in turn are used to update national seismic design maps used in the triennial update of model building codes. ANSS also includes structural monitoring, the data from which are used to support engineering research at NSF and NIST.

NSF and USGS support geoscience research to develop physics-based models of earthquake generation processes, the factors controlling the fault rupture, and the propagation and amplification of seismic shaking.

NSF supports fundamental research in the various engineering fields and in the social sciences, the results of which are used to develop a knowledge base of earthquake engineering and socioeconomic information on the issues that impact decision making for mitigation and response efforts. Some of the fundamental knowledge gained from these NSF-supported efforts is used directly by FEMA in its implementation activities, while NIST performs applied research and development that transitions some fundamental research results into FEMA's implementation activities, thus bridging the gap between fundamental research and implementation.

In addition to serving this bridging role, NIST is responsible for earthquake engineering research to improve building codes and standards for new and existing buildings and lifelines infrastructure; advance seismic-resistant construction practices; develop measurement and prediction tools supporting performance-based design and assessment standards; and evaluate advanced technologies.

FEMA works with earthquake professionals, using experience gained in the field, to transition the knowledge from NEHRP research activities into recommended design provisions for model building codes and supplemental design guidance for those codes. FEMA then works with national model building code organizations and ultimately with state, local, tribal, and territorial governments to ensure that the NEHRP-developed recommendations are considered in national model building codes. As the recommended provisions are put into practice, experience gained in actual earthquakes is fed back into the continuous NEHRP developmental process.

The Program emphasis on pre-disaster preparedness and mitigation is consistent with observations made by the National Science and Technology Council in 2005[15], when it noted that "a primary focus on response and recovery is an impractical and inefficient strategy for dealing with [natural disasters]. Instead, communities must break the cycle of destruction and recovery by enhancing their disaster resilience."

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[15] Grand Challenges for Disaster Reduction—A Report of the Subcommittee on Disaster Reduction, June 2005. https://www.sdr.gov/docs/GrandChallengesSecondPrinting.pdf

Appendix

C

Strategic Plan Development

This appendix presents an overview of the guiding planning principles used to develop this Strategic Plan for NEHRP for FY22 through FY29. This Plan is the third such plan for NEHRP, the prior two are:

- FEMA 383: *Expanding and Using Knowledge to Reduce Earthquake Losses: Strategic Plan for the National Earthquake Hazards Reduction Program*, 2001-2005 (2003)
- *Strategic Plan for the National Earthquake Hazards Reduction Program*, FY2009-2013 (2008)

This Plan is a result of close collaboration between the NEHRP agencies that builds off the foundation created by the two previous plans, while aligning with current legislation and consensus reports. Successful strategic planning and Program accomplishment must be consistent with existing policies, based on realistic assumptions, and responsive to changing conditions. The pace of Program accomplishments will depend on the resources that are available to the Program agencies during the FY22-FY29 Plan period.

This Strategic Plan for NEHRP is built upon four coordinated strategic goals and eighteen supporting strategic objectives that support the Program policy, vision, and mission. The strategy establishes a specific integrated and coordinated approach for the development and accomplishment of Program activities. The four goals support a programmatic life cycle with a built-in feedback loop ensuring continual improvement in Program activities as follows:

- Goal 1: Where, how, and why is there seismic risk?
- Goal 2: Program outputs from Program activities aim to reduce earthquake consequences.
- Goal 3: Foster stakeholders to action to adopt Program outputs to reduce their seismic risk.
- Goal 4: Lessons learned from earthquakes provide the metric to assess areas of improvement.

Strategic Planning Principles

Several guiding principles were followed in developing the strategic goals, objectives, and anticipated outcomes. They are discussed below.

Defining the Program Foundation

This Plan is created for a modern NEHRP, with forward-looking goals and objectives, and Program activities that fit current national needs. In developing this Plan, the PCWG took an introspective look within the Program and sought answers to some challenging questions.

- What does the Program accomplish, specifically with regards to coordination and collaboration with other public and private efforts?
- What is the ultimate goal of the Program?
- To be successful, what should the Program measure, manage, and deliver, and how can the Program create a strategy which supports broad, interdisciplinary programmatic efforts?
- How does the Program identify key stakeholders critical to achieving desired Objectives? How can the Program best listen to and understand their needs and the most effective means of collaboration?
- As we concentrate within and across our traditional areas of expertise and programmatic activities, what potential blind spots might we be missing?

Developing the Strategy

In creating the strategy, the PCWG considered the timeline of notable actions related to an earthquake. Figure C-1 was developed to identify these notable actions, when they occur, and how they might integrate with one another. These actions were first categorized whether they are a pre- or post-event action (no priority was assigned). Pre- and post-event actions were further classified by the outcome of the action. Pre-event actions were based on whether the outcome of the action was discovery-based or solutions-based, and post-event actions based on whether the action supported the response or recovery processes. This mapping exercise was done to identify any gaps within the role and responsibilities of this Program. One concept that surfaced was that the Program needed to incorporate a feedback loop so that lessons learned from an earthquake can become source material for pre-event actions. This led to the development of Goal 4.

The other three goals were developed to support Program strengths while allowing flexibility to address any identified gaps, new directions, and changes to responsibilities, in keeping with the timeline given in the figure. Thus, the developed goals collectively follow the timeline of Program activities from Hazard and Risk Characterization to Post-event Analysis.

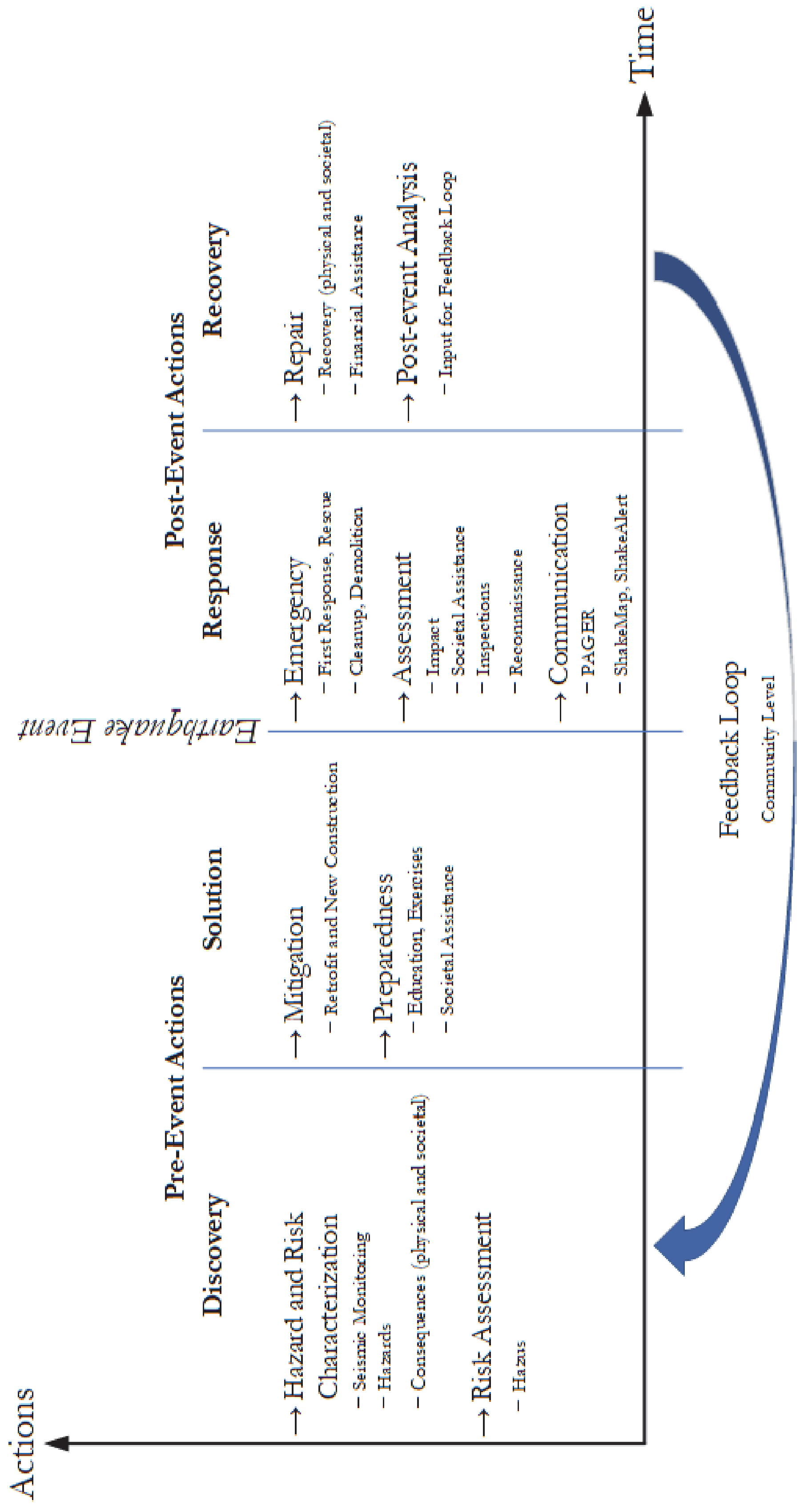

Figure C-1. Timeline of actions for an earthquake

In drafting the four goals and their supporting objectives, the PCWG had several conceptual aspirations:

- Simplify the understanding of the goals and objectives.
  - The public should understand the role of the Program and who we are. Redundancy in messaging to reinforce the vision throughout the strategic plan components.
  - Define what we need to measure and manage for the Program (e.g., facilitate developing the NEHRP biennial report to Congress).
  - Goals capture the essential Program actions for an earthquake (i.e., timeline presented above).
- Goals should be unique and mutually supportive.
  - The Goals should be broad enough that all Program agencies are included in each one.
  - View and evaluate the Program as a system; recognize that the agencies are individual but also interconnected components of the system.
  - Create Goals for the system that minimize risks from unintended consequences resulting from a component.
  - Goals should be used to identify the intended accomplishment of the strategy of Program activities.
- Use language to enhance positive awareness of Program activities.
  - For example, consider reframing "reducing hazard" to "increasing resilience".
- NEHRP has been in existence for over forty years, during which time significant advances have been made in earthquake monitoring and notification systems, earthquake hazard and risk assessments, earthquake resistant design and construction practices, and public awareness of the earthquake threat.
  - Goals should be developed to support the previous forty years while seeking a path for the future.

The Plan also draws upon several recently published documents and studies by others that make recommendations on future NEHRP directions. Examples of consensus studies and reports are as follows, but not limited to:

- Biennial reports of the Advisory Committee on Earthquake Hazard Reduction.[2]
- National Research Council. 2011. *National Earthquake Resilience: Research, Implementation, and Outreach*. Washington, DC: The National Academies Press.[3]

[2] ACEHR reports are available at https://www.nehrp.gov/committees/reports.htm
[3] https://doi.org/10.17226/13092

- National Academies of Sciences, Engineering, and Medicine. 2016. *State of the Art and Practice in the Assessment of Earthquake-Induced Soil Liquefaction and Its Consequences*. Washington, DC: The National Academies Press.[4]
- *NEHRP Recommended Seismic Provisions for New Buildings and Other Structures*, FEMA P-2082: Volume II: Part 3 Resource Papers. Federal Emergency Management Agency, Washington, DC.[5]
- *Earth in Time: A Vision for NSF Earth Sciences 2020-2030*, National Academies of Sciences, Engineering, and Medicine.[6]

Developing Program-Identified Focus Areas

In addition to the strategy presented in this Plan, the NEHRP agencies identified eight focus areas that address important stakeholder needs and require increased emphasis by the Program agencies during the Plan period. The focus areas reflect broader community needs and support general responsibilities as identified in the EHRA, as amended, or relevant legislation and executive orders. These focus areas have been identified as issues with serious public need coupled with impactful opportunities for innovation and advancement toward seismic risk reduction.

Generally, these topics are selected to fit the following criteria:

- knowledge gaps associated with critical vulnerabilities;
- congressional direction beyond that identified in legislation;
- agency or programmatic mission beyond current NEHRP legislative responsibilities; and
- key stakeholder needs identified in consensus studies.

In addition, Program identified focus areas have been influenced by:

- strategic goals and objectives;
- interagency programmatic activity coordination;
- supplemental funding initiative; and
- inter-programmatic coordination with relevant federal programs or agencies.

Figure C-2 illustrates how the focus areas interact with the strategy presented in this Plan. The strategy reflects congressional requirements as well as executive orders and is intended to guide the development and implementation of programmatic activities by the Program agencies. Legislation and executive orders contain either general or explicit responsibilities. Explicit responsibilities directly become programmatic activities whereas general responsibilities get filtered by the focus areas to

[4] https://doi.org/10.17226/23474
[5] https://www.fema.gov/sites/default/files/2020-10/fema_2020-nehrp-provisions_part-3.pdf
[6] https://www.nap.edu/catalog/25761/a-vision-for-nsf-earth-sciences-2020-2030-earth-in

become tactical programmatic activities. For example, the EHRA requires the Program to advance performance-based seismic design; this broad topic can be narrowed to develop a tactical activity though Focus Area 2.

Figure C-2. Interaction of the Program-Identified Focus Areas with the Strategy to Support NEHRP

Program activities to support these focus areas range from conducting fundamental and applied research, to developing cost-effective risk reduction measures, to promoting the implementation of these measures in practice. A Program activity may be a small effort that aligns with one or more objectives supporting a single goal, or it can be a larger multi-agency effort with several components supporting individual goals, which jointly span the full continuum of the strategy outlined in this Plan.

As an integral part of this approach, the Program must also be able to respond to change. Planning must be sufficiently broad and flexible to accommodate new ideas and technological innovations that may arise during the Plan period and accelerate progress toward supporting the Mission. With the guidance of ACEHR, the NEHRP agencies will regularly convene workshops and conduct forward-looking studies to identify technological opportunities or necessary paradigm shifts. New areas requiring attention or study may be revealed by investigations of the effects and impacts of recent earthquakes or relevant technological developments. When acted upon, recommendations and results of the workshops and studies will help to achieve the NEHRP vision.

Flexible and Realistic Plan Implementation

Successful strategic planning and Program accomplishment must be consistent with existing policies, based on realistic assumptions, and responsive to changing conditions. Following the adoption of this Plan, the NEHRP agencies will jointly develop a Management Plan that details Strategic Plan implementation activities that are consistent with agency appropriations and priorities.

Coordination and Cooperation among the NEHRP Agencies

There is no single congressional appropriation for NEHRP, nor does the NEHRP Office at NIST control the other three Program agency budgets, personnel, or activities. Consequently, the NEHRP agencies have agreed on coordinated Program planning, with coordinated budget review, which is focused on the result of iterative programmatic coordination amongst the agencies. It will, for example, be necessary to reexamine Program activities as annual estimated agency budgets are submitted. Adjustments to proposed NEHRP activities will be made, as appropriate, after agencies receive their appropriations. This coordination measure provides Program cost-effectiveness by expanding interagency synergy and cooperation in Program activities. This measure will also draw on the complementary strengths of the NEHRP agencies, providing a basis for them to work in concert, without duplicative efforts, toward common objectives and cost-effective impacts, thus achieving together more than they could individually.

Close Partnership with the Earthquake Professional Community

NEHRP strives to conduct its Program activities in concert with the earthquake professional community, including the public and private sectors, and to develop a national consensus on important NEHRP products. Three examples of this partnership approach are the National Seismic Hazard Maps (produced by USGS), the HAZUS loss-estimation model, work on improving new construction as represented by the *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures* (FEMA P-2082), produced through the Building Seismic Safety Council funded by FEMA and actively supported by USGS and NIST, and work on existing buildings, such as the development of updates to American Society of Civil Engineers (ASCE) 41: *Seismic Evaluation and Retrofitting of Existing Buildings*, currently being prepared by the Applied Technology Council (ATC) in the FEMA-funded ATC-140 project. In addition to being state-of-the-art technical guidance products, these products also serve as the entry point for new information into the nation's consensus design standards. For new buildings, the consensus standard is ASCE 7: *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*. For existing buildings, the consensus standard is ASCE 41. These standards have been developed through consensus processes involving the nation's leading earthquake professionals and their professional organizations. These products serve as the basis for earthquake-resistant provisions in national model building codes, such as those published by the International Code Council, that have been adopted in whole or in part in all 50 states. The NEHRP agencies work actively with national and international building codes and standards organizations to ensure that NEHRP-developed knowledge and technology are available for adoption. NEHRP agencies carefully monitor the progress of their products through the standardization process and adjust their future support activities to address problems and gaps in knowledge. This work will continue, as will open dialog with earthquake professionals through workshops, technical committees, Internet interaction, and other approaches.

While NEHRP is a federal program of coordinated efforts by the four Program agencies, most implementation efforts occur at the state, local, tribal, and territorial levels, through activities such as building code adoption, zoning, and response and recovery planning. The states, territories, tribes, private sector, universities, and regional, voluntary, and professional organizations contribute very significantly to earthquake risk reduction efforts and are frequent partners in NEHRP activities. Earthquake professionals in these organizations have much to offer NEHRP. This community of professionals has been highly supportive of NEHRP and continues to be indispensable to its effectiveness. The NEHRP agencies will sustain and enhance these partnerships and create new partnerships to accelerate the application of earthquake loss reduction in the United States.

Maximum Use of Research and Data Collection Facilities

The Plan proposes to take maximum advantage of new advanced research facility and data collection networks that have become partially or fully available in recent years, particularly the ANSS, the GSN, and NSF-supported earthquake engineering and geoscience facilities and centers.

USGS is deploying ANSS to integrate, modernize, and expand earthquake monitoring nationwide. The ANSS plan calls for the installation and maintenance of approximately 7,000 new seismic stations and sensors to measure ground and building response to seismic shaking. As of 2021, ANSS is about 50 percent complete in terms of instrument deployment. Despite the slow pace of instrumentation purchase and deployment, ANSS has made significant strides in integrating and standardizing seismic monitoring, data collection, and earthquake notification nationwide. Through ANSS, previously uncoordinated monitoring efforts across the Nation have been brought together in a single system. ANSS is currently developing coordinated national and regional data processing facilities for consistent and rapid notification of earthquake occurrence and impact (e.g., the ANSS Comprehensive Earthquake Catalog, or ComCat[7]) while providing valuable data and products critical for research and emergency response.

NHERI is a shared network of experimental facilities, collaborative tools, a centralized research data repository, and earthquake simulation software. NSF developed NHERI to improve our understanding of earthquakes and their effects on buildings, lifelines infrastructure, and other structures and to develop design and construction techniques to reduce and mitigate the impacts of these effects. This pioneering design allows testing facilities and results to be shared among researchers and practitioners, both nationally and internationally. NHERI represents a dramatic stride forward in earthquake engineering research capability, coordination, and cooperation.

USGS and NSF jointly developed and support the GSN, which provides data from more than 150 seismic stations around the globe, providing worldwide data for earthquake analysis and notifications, to assess tsunami potential and warnings, earth science research, and nuclear test treaty verification. GSN station deployment was completed in 2007.The GSN has entered its long-term operational phase in which system maintenance and periodic upgrades will be required to maintain its state-of-the-art

[7] https://earthquake.usgs.gov/data/comcat/

capabilities.

NEHRP recognizes that technical data on ground shaking from well-maintained earthquake monitoring networks such as ANSS and the GSN provide the quantitative foundation for developing earthquake resilience techniques and strategies.

Multidisciplinary, All-Hazards Approach

This Plan is multidisciplinary in its approach, fostering interactions in applying multiple technical disciplines to solve earthquake hazard mitigation problems. For example, research and development in separate technical fields, such as structural and geotechnical engineering, will be linked to maximize Program effectiveness. Societal issues related to implementing engineering measures, and response and recovery activities, will not be ignored.

Recent disasters have shown clearly that social, policy, economic, and engineering issues faced by NEHRP have many parallels with and connections to other extreme events associated with different large-scale disasters. Indeed, NEHRP leaders examined issues associated with the Nation's response to Hurricane Katrina in formulating this Plan. Multi-hazard planning and engineering have become national priorities. In terms of specific engineering issues (e.g., structural design), cascading effects when infrastructure lifeline components fail, and societal response to both natural (e.g., wind, tsunami) and man-made (e.g., explosion) hazards, there are many opportunities for synergy among research and implementation activities associated with different hazards. NEHRP strives to identify the areas of potential synergy with activities associated with other hazards, to improve the use of information gained from studies of other hazards in earthquake-related activities, and to determine where NEHRP advances can be of benefit to efforts to address issues related to other hazards. NIST for example routinely collaborates with wind hazard deployments to learn lessons regarding the built environment, but also important lessons concerning the social aspects of hazard events. Communication, dislocations and prompt recovery processes are common elements to hazards that illustrate strategies that work. It is essential for NEHRP actions to include facilitating knowledge transfer from experiences with other natural hazard incidents and the Nation's response to them to earthquake preparedness. This approach includes examining ways that knowledge gained in NEHRP activities can be transferred to successful mitigation of other hazards.

Linkages with Broader and Related Federal Policies, Plans, and Priorities

NEHRP links to broader government planning and coordination activities. Foremost among these linkages is the multiagency Science for Disaster Reduction (SDR), an interagency working group under the Subcommittee for Resilience Science and Technology (SRST) of the National Science and Technology Council (NSTC)[8]. The SDR was formerly known as the Subcommittee on Disaster Reduction. The SDR advises and assists the SRST and the NSTC on policies, procedures, plans, issues,

[8] https://www.sdr.gov/index.html

scientific developments, and research needs to facilitate and promote natural and technological disaster mitigation, preparedness, response, and recovery. NEHRP is engaged in the activities of the SDR and interacts with the SDR on matters related to earthquake effects mitigation.

The SDR published *Grand Challenges for Disaster Reduction* [9], which delineates national priorities for creating and sustaining disaster-resilient communities, considering various natural and technical hazards. These priorities and their links to the NEHRP Strategic Goals are:

1. Provide hazard and disaster information where and when it is needed (NEHRP Strategic Goal 3).
2. Understand the natural processes that produce hazards (NEHRP Strategic Goal 1).
3. Develop hazard mitigation strategies and technologies (NEHRP Strategic Goals 2).
4. Recognize and reduce vulnerability of interdependent critical infrastructure (NEHRP Strategic Goals 1, 2 and 3).
5. Assess disaster resilience using standard methods (NEHRP Strategic Goal 2).
6. Promote risk-wise behavior (NEHRP Strategic Goal 3).

NEHRP Strategic Goal 4 supports all the above listed priorities.

The SDR Earthquake *Grand Challenge* implementation plan[10] outlines priority science and technology implementation actions specific to earthquakes. The SDR implementation plan is consistent with and complements the statutory responsibilities of NEHRP, as well as this Strategic Plan.

Other federal agencies and programs benefit from NEHRP activities, like the National Oceanic and Atmospheric Administration (NOAA) and the National Aeronautics and Space Administration (NASA), both through the application of new NEHRP-developed technologies and the adoption of model building code provisions. In general, NEHRP interacts with the other agencies through the ICSSC. Similarly, other federal agencies often engage in agency-unique seismic research or application work that can complement or augment NEHRP work with their unique capabilities. The NEHRP agencies engage cooperatively with those efforts as opportunities arise.

Other agencies are engaged in earthquake risk reduction activities that address specific needs such as those associated with transportation infrastructure, dams, nuclear power facilities, and other critical elements of the built environment. Where appropriate, NEHRP will cooperate with these agencies and apply relevant results from their program efforts to enrich NEHRP activities.

Increased International Cooperation

The results of NEHRP activities provide knowledge and tools that the United States can make

[9] https://www.sdr.gov/docs/GrandChallengesSecondPrinting.pdf
[10] https://www.sdr.gov/grandchallenges.html or https://www.sdr.gov/docs/185820_Earthquake_FINAL.pdf

available to assist other nations that have been unable to develop comprehensive earthquake research and mitigation activities. In contrast, some nations have had great success in earthquake research and mitigation, providing opportunities for NEHRP to develop mutually beneficial strategic partnerships. Some international partnerships already exist, at the agency level and at the broader NEHRP level. In all aspects of its research, implementation, and education efforts, NEHRP strives to develop and continue appropriate international partnerships. Ongoing cooperative activities include participating in the U.S.-Japan Panel on Wind and Seismic Effects and the U.S.-Japan Natural Resources Panel on Earthquake Research; conducting joint workshops with the China Earthquake Administration; creating research partnerships with the Japanese National Research Institute for Earth Science and Disaster Prevention; and performing seismic hazard assessments for Afghanistan. Details of these and other similar efforts are provided in the NEHRP annual or biennial reports.

To coordinate the international aspects of the GSN, USGS, NSF, and operators of the Seismological Facilities for the Advancement of Geoscience (SAGE) award will continue to work closely with the international Federation of Digital Seismic Networks to set data and metadata standards for digitally recording seismic stations.

Service to the Public

Above all else, NEHRP exists to serve the nation. In fulfilling the NEHRP mission of creating an earthquake-resilient nation, NEHRP will openly engage and serve the public. Many of NEHRP's efforts target the earthquake professional community, which in turn serves the public. In addition, direct public outreach, knowledge and technology transfer, and education and training are essential elements of NEHRP. These activities will be accomplished by providing general information on earthquake hazards, specific information on local and regional earthquake threats, practical information on earthquake mitigation, and notification of earthquake occurrences and their impacts. Examples of public engagement activities are homeowner's guides to earthquake safety, newspaper inserts describing the regional earthquake risk, publications on earthquake scenarios and estimated impacts, and web-based products showing the distribution and severity of earthquake shaking within minutes of an event. Finally, NEHRP leaders strive to ensure that all aspects of the Program are transparent and always open to public reflection and feedback. Relevant information is frequently posted on the Program website (www.nehrp.gov) and means for the public to communicate with NEHRP leaders will always be clear, open, and available.

Appendix

D

Earthquake Hazards Reduction Act

Table D-1 provides a list of the amendments to the Earthquake Hazards Reduction Act of 1977 (Public Law 95-124, 42 U.S.C. 7701 *et. seq*.).

Table D-1. Reauthorizations of the Earthquake Hazards Reduction Act

Date of Enactment	Public Law	U.S. Statute Citation	U.S. Legislative Bill	President
October 7, 1977	P.L. 95-124	91 Stat. 1098	S. 126	Jimmy E. Carter
October 19, 1980	P.L. 96-472	94 Stat. 2257	S. 1393	Jimmy E. Carter
November 20, 1981	P.L. 97-80	95 Stat. 1081	S. 999	Ronald W. Reagan
January 12, 1983	P.L. 97-464	96 Stat. 2533	S. 2273	Ronald W. Reagan
March 22, 1984	P.L. 98-241	98 Stat. 95	S. 820	Ronald W. Reagan
September 30, 1985	P.L. 99-105	99 Stat. 475	S. 817	Ronald W. Reagan
February 29, 1988	P.L. 100-252	102 Stat. 18	S. 1612	Ronald W. Reagan
November 16, 1990	P.L. 101-614	104 Stat. 3231	S. 2789	George H.W. Bush
October 19, 1994	P.L. 103-374	108 Stat. 3492	H.R. 3485	William J. Clinton
October 1, 1997	P.L. 105-47	111 Stat. 1159	S. 910	William J. Clinton
November 13, 2000	P.L. 106-503	114 Stat. 2298	H.R. 1550	William J. Clinton
October 25, 2004	P.L. 108-360	118 Stat. 1668	H.R. 2608	George W. Bush
December 11, 2018	P.L. 115-307	132 Stat. 4480	S. 1768	Donald J. Trump

A full-form version of the Earthquake Hazards Reduction Act as amended through Public Law 115-307 can be found following the link below.

https://www.nehrp.gov/pdf/NEHRP Public Law 115-307.pdf