Annual Report of the National Earthquake Hazards Reduction Program for Fiscal Year 2012

February 2014


FEMA

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

USGS
science for a changing world

This report about the National Earthquake Hazards Reduction Program (NEHRP) during fiscal year 2012 is submitted to Congress by the Interagency Coordinating Committee (ICC) of NEHRP, as required by the National Earthquake Hazards Reduction Act of 1977(42 U.S.C. 7701et seq. as amended by the Earthquake Hazards Reduction Program Reauthorization Act of 2004 (Public Law 108-360).

The members of the ICC are as follows:

Chair
Dr. Patrick D. Gallagher
Under Secretary of Commerce for Standards and Technology
and Director
National Institute of Standards and Technology
U.S. Department of Commerce

Mr. W. Craig Fugate
Administrator
Federal Emergency Management Agency
U.S. Department of Homeland Security

Dr. Cora B. Marrett
Acting Director
National Science Foundation

Ms. Sylvia Mathews Burwell
Director
Office of Management and Budget
Executive Office of the President

Dr. John P. Holdren
Assistant to the President for Science and Technology
and Director
Office of Science and Technology Policy
Executive Office of the President

Dr. Suzette M. Kimball
Acting Director
U.S. Geological Survey
U.S. Department of the Interior

Disclaimer: Certain trade names or company products are mentioned in the text to specify adequately the experimental procedure and equipment used. In no case does such identification imply recommendation or endorsement by any of the agencies represented on the ICC, nor does it imply that the equipment is the best available for the purpose.

Table of Contents

Executive Summary

This is the annual report of the National Earthquake Hazards Reduction Program (NEHRP) for fiscal year (FY) 2012,[1] presented by the NEHRP Interagency Coordinating Committee (ICC). This report, required by Public Law 108–360, describes the 2012 activities of the NEHRP agencies, and their progress toward reducing the impacts of future earthquakes in the United States. The report also lists program budgets for FY 2013 and those proposed for FY 2014.

The four Federal agencies participating in NEHRP 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). NIST serves as the NEHRP lead agency and the Director of NIST chairs the ICC. Within NEHRP, the participating agencies have distinct roles and responsibilities that are mutually dependent and supportive.

The NEHRP ICC is composed of the Administrator of FEMA, the Directors of NIST, NSF, and USGS, and the Directors of the White House Office of Science and Technology Policy and Office of Management and Budget.

Some of the significant NEHRP activities and accomplishments of 2012 are outlined briefly below.

USGS has been actively studying the characteristics of the increased seismicity that is, in some cases, associated with the injection into the earth of waste fluids from hydraulic fracturing ("fracking") activities. USGS is studying these earthquakes and nearby industrial activities to determine what distinguishes an injection activity that causes earthquakes large enough to be felt from the vast majority of injection operations that do not induce earthquakes of any consequence.

In its National Strong Motion Instrumentation Project, USGS has partnered with the Veterans Administration, the California Geological Survey, and others to install state-of-the-art seismic monitoring systems in buildings located in seismically active regions around the United States. Such instrumentation will provide valuable information about the responses of real buildings in future earthquakes—in effect providing "full-scale" structural laboratories. Data from these instruments will help in evaluating the safety and serviceability of hospitals and other buildings following an earthquake.

NSF and FEMA are both addressing critical issues regarding nonstructural systems in critical buildings such as hospitals that are key to their functionality. Such systems include piping; ductwork

[1] This report covers FY 2012 as defined by the Federal Government, a period that began on October 1, 2011, and ended on September 30, 2012. For convenience and readability, "FY" is not repeated in subsequent references to this period, except in budget discussions. Consequently, all references to the year 2012 should be interpreted as FY 2012 unless calendar year 2012 is specified.

for heating, ventilating, and air conditioning systems; and medical diagnostic equipment that is essential to the functionality of hospitals, among many other items. Researchers at the University of California (UC) San Diego conducted a series of full-scale tests on the UC San Diego outdoor shake table (an NSF George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) facility) that subjected nonstructural systems found commonly in hospitals to earthquake simulations, thus providing valuable information on the performance of such systems in earthquakes. In a parallel but closely related activity, FEMA released an update to its guide entitled *Reducing the Risks of Nonstructural Earthquake Damage* and provided webinar training on how to use the guide. The training was viewed across the United States.

The NEHRP agencies continued their efforts to assess the implications of recent damaging earthquakes in Chile, Japan, and New Zealand for buildings and infrastructure in the U.S. With NSF support, the Earthquake Engineering Research Institute conducted a researcher workshop to identify the future research needs and directions that emerged from over 50 NSF-supported projects undertaken to gather perishable field data following earthquakes in New Zealand and Chile. NIST continued its development of a prototype post-disaster database, based on information gathered by various U.S. teams following the 2010 Maule, Chile earthquake. The database development utilizes the NEEShub technology developed by Purdue University with NSF support.

To foster well-integrated interdisciplinary research focused in hazards-related science and engineering, NSF launched its new Interdisciplinary Research in Hazards and Disasters (Hazards SEES) program. This is a multi-directorate NSF program that seeks to advance understanding of fundamental processes associated with hazards as well as the effects of hazards on individuals, society, and the natural and built environments. It also seeks to improve the capabilities needed to mitigate, respond to, and recover from the effects of these hazards.

USGS continues to expand its efforts to provide rapid dissemination of information to the public when earthquakes occur. Among several key "situational awareness" products is ShakeCast, a freely available, post-earthquake situational awareness application that automatically retrieves earthquake shaking data provided by the ShakeMap system. ShakeMap estimates the distribution and severity of ground shaking within a few minutes after an earthquake. ShakeCast compares the ShakeMap shaking intensity estimates with user-specified vulnerability criteria, to facilitate damage assessment and assist with emergency management. A diverse clientele of users continues to grow—among them are the Port of Long Beach, the Los Angeles County Department of Public Works, the Nuclear Regulatory Commission, the International Atomic Energy Agency, Walmart, Target, and Degenkolb Engineers. Paralleling the development and implementation of ShakeCast, USGS is also working with researchers in California and Washington, with support from the Gordon and Betty Moore Foundation, to complete the initial development of a ShakeAlert earthquake early warning system that can be integrated with existing components of the Advanced National Seismic System.

Led by FEMA and USGS, the NEHRP agencies enhanced their efforts to improve national earthquake awareness and preparedness via support for the ShakeOut earthquake preparedness drills, which began in California in 2008 and continue to grow in popularity and impact. In October

2011, over 10 million people in Arizona, California, Guam, Idaho, Nevada, and Oregon participated in ShakeOut drills. In October 2012, more than 17 million people participated in ShakeOut drills in the United States and its territories (an additional 2.2 million people participated in other countries).

Section 1
Introduction

The National Earthquake Hazards Reduction Program (NEHRP) is a multiagency program established by Congress "to reduce the risks of life and property from future earthquakes in the United States." The four Federal agencies participating in NEHRP 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). NIST serves as the lead agency for NEHRP.

NEHRP was initially authorized by Congress in 1978. Since then, Congress has periodically reauthorized the program, generally at 2- to 5-year intervals. The latest reauthorization of NEHRP (Public Law 108–360, the Earthquake Hazards Reduction Program Reauthorization Act of 2004) authorized funding for the four participating agencies through fiscal year (FY) 2009. Pending the passage of new reauthorizing legislation, the NEHRP agencies continue to perform their duties as outlined in Public Law (PL) 108–360, within budget allocations that are less than the authorized funding levels for FY 2009.

PL 108–360 requires that the NEHRP Interagency Coordinating Committee (ICC), which directs the program, submit an annual report on NEHRP budgets and activities. The ICC submits this annual report, covering 2012,[2] pursuant to that requirement.

Previous NEHRP annual reports provide detail on the organizational structure of NEHRP and agency roles and responsibilities. That information, as well as much greater detail regarding NEHRP, is provided at www.nehrp.gov. This NEHRP annual report for 2012 provides information on NEHRP budgets, 2012 statutory program activities, state activities promoting implementation of research results, and related non-NEHRP activities that support NEHRP goals.[3] This report and prior NEHRP annual reports are available at www.nehrp.gov/about/reports.htm.

With the exception of a magnitude 7.1 (M7.1) earthquake in eastern Turkey, 2012 was a quiet year worldwide for significant damaging earthquakes. Within the United States, only minor damage was reported from earthquakes in Oklahoma and California in 2012.

[2] This report covers FY 2012 as defined by the Federal Government, a period that began on October 1, 2011, and ended on September 30, 2012. For convenience and readability, "FY" is not repeated in subsequent references to this period, except in budget discussions. Consequently, all references to the year 2012 should be interpreted as FY 2012 unless calendar year 2012 is specified, and, unless otherwise noted, all activities described took place during FY 2012.

[3] FEMA-related activity information in this report was extracted from "The National Earthquake Hazards Reduction Program: FEMA Accomplishments in Fiscal Year 2012," issued by FEMA in April 2013.

This does not mean that the Nation should become complacent regarding its preparations for future earthquakes. The last event causing major, widespread damage in the United States occurred near Northridge, CA, in 1994. Since then, nearly an entire generation of young adults has not experienced or witnessed a major, damaging earthquake in this country. However, during this time the tectonic forces that cause earthquakes have continued to build up stress in the Earth's crust, making the question of future earthquakes in the United States not one of "if" but "when." While this pause in major seismic activity has given us more time to prepare for the next large event, when such damaging events are "out of sight and out of mind" for many years, the public and government officials can become complacent regarding the earthquake hazard and associated risks. A primary role of NEHRP is to provide stable and consistent leadership and resources for the development of new, cost-effective mitigation measures and to advocate for their implementation. The NEHRP agencies cannot prevent future earthquakes in the United States, but the continued efforts of the agencies will help the Nation prepare for their eventual occurrence, survive them safely, and reduce their impacts on society, including life and property, thus improving societal resilience.

Section 2
Program Budgets

PL 108–360 requires that NEHRP annual reports include, for each agency participating in the program and for each program "activity" defined in the legislation, a program budget for the current fiscal year (i.e., the year following that covered in the report) and a proposed program budget for the next fiscal year. The "Strategic Plan for the National Earthquake Hazards Reduction Program, Fiscal Years 2009–2013," published in October 2008 (www.nehrp.gov/pdf/strategic_plan_2008.pdf), defined three major goals for the program that encompass all but one of the program activities defined in PL 108–360. The remaining activity, which concerned the development, operation, and maintenance of NEHRP facilities, was incorporated directly into the strategic plan. Table 2–1 shows the relationships between the congressionally defined program activities and the goals and activities that are included in the strategic plan.

Program budgets for the current fiscal year (FY 2013) are presented in Table 2–2, which shows the funding that each participating agency is directing toward the goals and activities specified in the strategic plan. Table 2–3 identifies the agency funding requested or anticipated for NEHRP in FY 2014. Funds budgeted for the development, operation, and maintenance of NEHRP facilities are allocated among the Advanced National Seismic System (ANSS), the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES), and the Global Seismographic Network (GSN).

Table 2–1. Relationships of NEHRP strategic goals to statutory program activities.

NEHRP Strategic Goals	Statutory Program Activities*
Goal A: Improve understanding of earthquake processes and impacts.	Improve the understanding of earthquakes and their effects on communities, buildings, structures, and lifelines, through interdisciplinary research that involves engineering, natural sciences, and social, economic, and decision sciences.
Goal B: Develop cost-effective measures to reduce earthquake impacts on individuals, the built environment, and society at large.	Develop effective measures for earthquake hazards reduction.
Goal C: Improve the earthquake resilience of communities nationwide.	Promote the adoption of earthquake hazards reduction measures by Federal, state, local governments, and others.
Develop, operate, and maintain NEHRP facilities.	Develop, operate, and maintain ANSS, NEES, and the GSN.

* As defined by Congress in PL 108–360.

2.1 NEHRP FY 2013 Budgets by Strategic Goal

Table 2–2 lists the FY 2013 NEHRP budgets, by strategic goal, for the NEHRP agencies: Federal Emergency Management Agency (FEMA), National Institute of Standards and Technology (NIST), National Science Foundation (NSF), and U.S. Geological Survey (USGS).

Table 2–2. NEHRP agency budgets for FY 2013.

Strategic Goal	FY 2013 Funds Allocated to Goal ($M)[1]				
	FEMA[2]	NIST[3]	NSF[4]	USGS[5]	**Total**
Goal A: Improve understanding of earthquake processes and impacts.	0.1	0.3	48.7	10.2	**59.3**
Goal B: Develop cost-effective measures to reduce earthquake impacts on individuals, the built environment, and society at large.	3.7	3.0		17.7	**24.4**
Goal C: Improve the earthquake resilience of communities nationwide.	3.9	0.6		14.6	**19.1**
Develop, operate, and maintain NEHRP facilities:					
ANSS—USGS				8.3	**8.3**
GSN—NSF and USGS			3.5	4.9	**8.4**
Total:	**7.7**	**3.9**	**52.2**	**55.7**	**119.5**

Notes on Table 2–2:

[1] Budgets are rounded to the nearest $0.1 million.

[2] The FEMA FY 2013 budget is an allocation from the U.S. Department of Homeland Security (DHS) appropriation that covers NEHRP activities but excludes employee salaries and expenses (S&E).

[3] The NIST FY 2013 budget is an allocation from the NIST appropriation that covers all NEHRP-related activities, including the NEHRP Lead Agency role and Earthquake Risk Reduction R&D activities.

[4] The NSF FY 2013 budget is an allocation from the NSF appropriation that covers NEHRP activities but excludes Agency Operations and Award Management (AOAM). The NSF budget includes support for the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES).

[5] The USGS FY 2013 budget is a line item in the USGS appropriation that covers NEHRP activities. The amount reported for ANSS in the table is the information technology cost (only), as tracked in the Exhibit 300 for ANSS.

2.2 NEHRP FY 2014 Budget Requests by Strategic Goal

Table 2–3 lists the FY 2014 NEHRP planning budgets for each agency by strategic goal. These figures are based on agency submissions included in the President's FY 2014 budget request to Congress.

Table 2–3. NEHRP agency budget requests for FY 2014.
(See notes 2–5 below for explanation of agency NEHRP "budget requests")

Strategic Goal	FY 2014 Funds Requested or Anticipated for NEHRP Goals ($M)[1]				
	FEMA[2]	NIST[3]	NSF[4]	USGS[5]	**Total**
Goal A: Improve understanding of earthquake processes and impacts.	0.1	0.3	49.7	11.7	**61.8**
Goal B: Develop cost-effective measures to reduce earthquake impacts on individuals, the built environment, and society at large.	3.7	3.0		20.3	**27.0**
Goal C: Improve the earthquake resilience of communities nationwide.	3.9	0.6		16.8	**21.3**
Develop, operate, and maintain NEHRP facilities:					
ANSS—USGS				9.1	**9.1**
GSN—NSF and USGS			3.5	5.2	**8.7**
Total:	**7.7**	**3.9**	**53.2**	**63.1**	**127.9**

Notes on Table 2–3:

[1] Budgets are rounded to the nearest $0.1 million.

[2] The FEMA FY 2014 budget is a planned allocation from the U.S. Department of Homeland Security (DHS) appropriation that covers NEHRP activities but excludes employee salaries and expenses (S&E).

[3] The NIST FY 2014 budget is a planned allocation from the NIST appropriation that covers all NEHRP-related activities, including the NEHRP Lead Agency role and Earthquake Risk Reduction R&D activities.

[4] The NSF FY 2014 budget is a planned allocation from the NSF appropriation that covers NEHRP activities but excludes Agency Operations and Award Management (AOAM). The NSF budget includes support for the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES).

[5] The USGS FY 2014 budget is a line item in the USGS appropriation that covers NEHRP activities. The amount reported for ANSS in the table is the information technology cost (only), as tracked in the Exhibit 300 for ANSS.

Section 3
2012 Activities and Results

The organization of this chapter follows that of the NEHRP strategic plan for fiscal years 2009–2013. The strategic plan defines NEHRP in terms of broad strategic goals and more specific objectives and related strategic priorities. The goals are directly linked to the NEHRP activities defined in PL 108–360, Section 103(2). Key outcomes for each goal are also listed in the plan. By following the structure of the strategic plan, this report allows the reader to directly assess how accomplishments in 2012 are furthering progress toward the stated goals and objectives. Accomplishments are not categorized by NEHRP agency but rather are cast in terms of collective progress based on cooperative efforts.

3.1 Goal A: Improve Understanding of Earthquake Processes and Impacts

Understanding how and why earthquakes occur and what happens to our communities when they do is an essential step in building the knowledge required to reduce the consequences of future earthquakes. For this reason, NEHRP supports basic research related to earthquakes in geoscience, engineering, and social science. The research supported and undertaken under Goal A provides a strong foundation for the development and implementation of practical earthquake risk-reduction measures pursued under the other strategic goals. Strategic Goal A is directly related to the congressionally defined NEHRP program activity "Improve understanding of earthquakes and their effects on communities, buildings, structures, and lifelines through interdisciplinary research that involves engineering, natural sciences, and social, economic, and decision sciences." Program accomplishments for 2012 are listed under the four objectives established for Goal A in the strategic plan.

Objective 1: Advance understanding of earthquake phenomena and generation processes

SCEC3: Improving our understanding of seismic hazards in California

In 2012, the Southern California Earthquake Center (SCEC) completed the 5-year SCEC3 research program, funded by NSF and USGS, which sought better understanding of seismic behavior in southern California. This research has advanced and combined scientific knowledge toward a comprehensive understanding of earthquake phenomena, leading to major advances in the following areas:

- Unified structural representation—unified, three-dimensional representations of active faults and earth structure (velocity, density, etc.) for use in fault-system analysis, ground-motion prediction, and hazard assessment.
- Extended earthquake rupture forecasting—developing a physics-based approach to earthquake rupture forecasts (i.e., determining how likely earthquakes are to occur).

- Broadband ground motion prediction—validation of strong ground motion predictions based on a fundamental, physics-based understanding of earthquake rupture and seismic wave propagation. The critical tie between improved earthquake rupture forecasts and earthquake risk reduction is accurate ground motion prediction.

The 5-year SCEC4 program was also launched in 2012 to continue this important research. Areas of focus include:

- Stress transfer from plate motion to crustal faults, especially long-term slip rates;
- Stress-mediated fault interactions and earthquake clustering;
- Evolution of fault resistance during seismic slip;
- Structure and evolution of fault zones and systems and their relation to earthquake physics;
- Causes and effects of transient deformations, such as slow slip events and tectonic tremor; and
- Seismic wave generation and scattering for prediction of strong ground motions.

Developing the Uniform California Earthquake Rupture Forecast, version 3 (UCERF3)

Over the past 3 years, a large group of geologists, geodesists, geophysicists, and engineers from academia, industry, and government have been developing a new earthquake forecast model for California under the Working Group on California Earthquake Probabilities (WGCEP). This effort is led by USGS, coordinated by SCEC, and partially funded by the California Earthquake Authority. UCERF3 is a comprehensive earthquake probability model that addresses shortcomings identified in the 2008 WGCEP model UCERF2. The main goals for UCERF3 are to relax fault segmentation, include multi-fault rupture modeling (the need for which was recently exemplified by the 2011 M9.0 Great East Japan (Tohoku-Oki) and 2012 M8.6 Sumatra earthquakes), and include spatiotemporal clustering (triggered events and aftershocks, the implications of which were exemplified by the 2011 M6.3 Christchurch earthquake). Modeling such behavior will require deploying UCERF3 as an operational earthquake forecast model. Other innovations include a major overhaul of the California fault database, incorporation of GPS geodesy in the fault deformation model, and a new mathematical framework for determining the earthquake rupture rate for the entire fault system based on the geological, geodetic, and seismological inputs.

Learning about creeping fault segments and large earthquakes

Scientists have long believed that some sections of faults are relatively stable, creeping (moving slowly and continuously) rather than rupturing in catastrophic earthquakes. Researchers at Caltech, supported by NSF, have recently found that such supposedly stable segments can behave differently when earthquake ruptures penetrate them from adjacent sections of faults. This assessment was based on state-of-the-art modeling that incorporated the entire range of observed fault behaviors, including earthquake nucleation, dynamic rupture, postseismic slip, interseismic deformation, and patterns of large earthquakes. Scientists believe that such activation of a presumed stable fault segment happened during both the 1999 M7.6 Chi-Chi earthquake in Taiwan, which occurred in an

area previously believed to be stable, and the 2011 M9.0 Great East Japan Earthquake, which was much larger than scientists previously believed possible in that area. This research may indicate that California's San Andreas Fault could experience larger earthquakes than are accounted for in current seismic hazard maps.

Studying induced seismicity from natural gas production

USGS completed, with support from the Environmental Protection Agency, a study of the Trinidad, CO, earthquake sequence, which began in August 2001 and included a M5.3 event. This study concluded that the Trinidad earthquakes were due primarily to deep injection of large volumes of wastewater associated with production of natural gas within the Raton Basin in southern Colorado and northern New Mexico. Although natural earthquakes are known to occur there, the dramatic increase in seismicity beginning in 2001 and continuing at least through 2011 was shown by correlation to be the result of a corresponding increase in the rate of wastewater injection.

More broadly, the rate of occurrence of earthquakes of M3 or greater in the midcontinent of the United States was observed to increase significantly beginning in about 2001. Whereas events in this magnitude range were occurring at average rates of 21 per year before 2001, the average rate from 2001 through 2011 was nearly 44 per year. This increase appears to represent induced earthquakes. Earthquake sequences near Trinidad, CO; Guy, AZ; and Prague, OK, locations of gas and oil production from newly accessible resources, account for a significant fraction of the increased seismicity in the midcontinent since early 2001.

Gas and oil production from low-permeability formations, enabled by recent developments such as horizontal drilling, has caused earthquakes by (1) hydraulic fracturing to enhance formation permeability and (2) the injection of wastewater, co-produced with the gas and oil, into deep aquifers. While earthquakes induced by hydraulic fracturing are almost all too small to be felt or reported, earthquakes induced by wastewater disposal are sometimes large enough to be of concern to the public. USGS continues to study these earthquakes and the industrial activities nearby to determine what distinguishes an injection activity that causes earthquakes large enough to be felt from the vast majority of injection operations that do not induce earthquakes of any consequence.

Simulating fault slip during earthquakes in the laboratory

Fault slip during a large earthquake releases elastic energy stored in the earth that has built up over time from tectonic forcing. The amount of energy released is controlled by the strength of the fault during slip. Researchers at USGS and the University of Oklahoma have developed a new method to simulate fault strength during this large energy release in flywheel-based laboratory faulting experiments. The experiments are proxies for faulting during earthquakes in the moment-magnitude range of M4 to M8 and indicate that imposed high acceleration increases dynamic weakening by intense wear of fault zones.

Understanding Pacific Northwest tectonics related to regional seismicity

USGS scientists have constructed a new representation of the Cascadia Seismogenic Zone in the Pacific Northwest, resulting in an image of the Juan de Fuca tectonic plate at the subsurface, where it is being forced beneath the North American continent. The image synthesizes depth information from earthquake locations and regional seismic velocity studies. The study reveals for the first time the spatial distribution of earthquakes and their relationship to ongoing plate subduction (when one tectonic plate overrides another). It finds significant spatial differences in the geometry of the subducting (lower) plate in northern, central, and southern portions of the region. Future improvements in our knowledge of the Pacific Northwest seismic zone are expected from the currently deployed network of ocean bottom seismometers (Cascadia GeoPRISMS) in this region.

Studying seismicity and shallow deformation at the Hanford Nuclear Reservation

In 2009, a swarm of small, shallow earthquakes occurred in southern Washington State, at the Hanford Nuclear site. The earthquakes were associated with significant deformation, detected at the earth's surface with data from the European Space Agency's ENVISAT satellite. A team of researchers from the USGS Earthquake Science Center, the Pacific Northwest Seismic Network, and the University of Washington found that the earthquakes were driven largely by shallow, predominantly aseismic fault slip. These results are in strict contrast to typical seismic sequences in California, where shallow earth deformation is predominantly seismic, and illustrate the complex relations among earthquake occurrence, earth deformation, and seismic hazard in the Pacific Northwest.

Studying triggered earthquakes: surprises from Sumatran Megathrust earthquakes

Several large earthquakes have occurred in the past decade on the Sunda Megathrust Fault (measuring hundreds of kilometers in length) offshore of Sumatra, Indonesia. Scientists supported by NSF have been modeling and measuring stress loading of this fault system to understand whether some of these earthquakes have triggered subsequent earthquakes by transferring stress to other fault segments. Characteristics of megathrust earthquakes on the fault system in 2000, 2004, 2005, and 2007 suggest that the earlier events may have triggered the 2007 event, but data analysis is inconclusive. Geodetic investigations are necessary to determine whether the increased level of seismicity has been associated with induced slipping of the Sunda megathrust, a potential contributing factor to the timing and location of the 2007 earthquake. The section of the Sunda megathrust offshore of central Sumatra, which last ruptured in 1797, still poses a large seismic hazard, threatening the city of Padang.

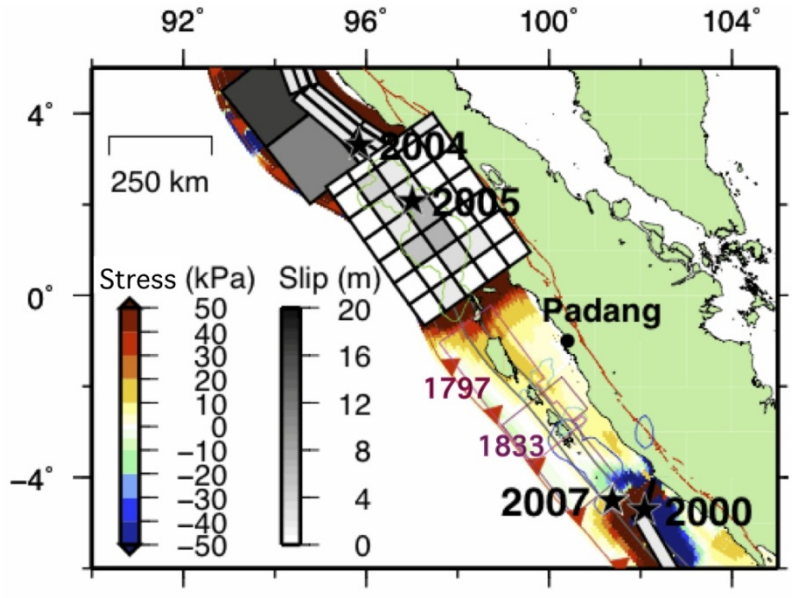


Figure 3–1. Total stress change on the Sunda megathrust from the combined 2000, 2004, and 2005 earthquakes. The warm colors indicate stress loading of the megathrust and the cool colors indicate stress relief. Another great earthquake is expected in the near future on the segment of the Sunda megathrust offshore of central Sumatra, which last ruptured in 1797 and was stressed by recent earthquakes. Image courtesy of NSF.

RAPIDS: uncovering evidence of major past Haitian earthquakes

The 2010 M7.0 earthquake was catastrophic for Haiti, causing about 230,000 casualties and devastating the capital and surrounding areas. Understanding the behavior and timing of major earthquakes like this one is crucial for protecting people and infrastructure around active fault zones. With support from an NSF Rapid Response Research (RAPID) grant, scientists discovered underwater evidence that the 2010 earthquake in Haiti may not have been the first of its kind in the region. Cores taken from the seafloor reveal a 2,000-year-old sequence of sediment layers that closely resemble landslide deposits triggered by the 2010 quake, indicating an older event of similar characteristics and violence.

Objective 2: Advance understanding of earthquake effects on the built environment

Recording building responses to earthquakes with seismic instruments

It is crucial to have recordings of building motions during earthquakes to better understand their behavior during shaking, improve designs of earthquake-resistant structures, and assess their state of health after earthquakes. The USGS National Strong-Motion Project (NSMP) has partnered with a number of institutions to instrument a range of buildings. The U.S. Department of Veterans Affairs (VA), which had hospitals damaged in earthquakes in 1971 and 1989, has partnered with the NSMP, installing strong-motion sensors in eight VA hospitals in Oregon, Nevada, Montana, Washington, Tennessee, and Puerto Rico. Plans were completed to instrument seven more VA hospitals in California, Illinois, Missouri, Oklahoma, South Carolina, Utah, and Virginia. The U.S. General Services Administration has also partnered with the NSMP, installing sensors in the San Diego Federal Courthouse.

Sensors have been installed in Boelter Hall at the University of California, Los Angeles, with funding from the USGS Advanced National Seismic System (ANSS). The Science and Engineering Building

at the University of Nevada Las Vegas (UNLV) campus was instrumented by the NSMP in collaboration with UNLV's Department of Civil and Environmental Engineering and Construction. The UNLV building is the first building in Las Vegas equipped with a sophisticated seismic monitoring system. With funding from ANSS, the NSMP, and the California Strong Motion Instrumentation Program of the California Geological Survey, sensors were cooperatively installed in the state-of-the-art One Rincon Hill building in San Francisco, a 64-story residential tower.

Figure 3–2. During 2012, significant effort went into installing seismic instrumentation in buildings. These instruments transmit both motion data and state-of-health information about the buildings over the Internet in near-real time for earthquake early warning and rapid post-earthquake safety assessments of the instrumented structures. This image shows the exterior of a recently instrumented building, One Rincon Hill, in San Francisco. Through a joint project between USGS and the California Geological Survey, this building now hosts 72 real-time strong motion sensors—the most dense instrumentation of any building in the United States. Image courtesy of Wikimedia Commons.

NEES shake table tests of five-story building with nonstructural components

Researchers conducted a series of tests using the large George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) outdoor shake table at the University of California (UC) San Diego to learn how to help high-value buildings, such as hospitals and data centers, remain operational after earthquakes. For a building to be operational after an earthquake, both the building's structural and nonstructural systems need to respond well to the shaking. As better building codes and standards have improved the structural systems in new buildings, damage to their nonstructural systems (e.g., piping, ductwork, ceilings, elevators) has emerged as a dominant source of potential earthquake-related losses. These were the first shake table tests of entire nonstructural systems at full scale, and they also examined the interaction between structural and nonstructural systems. This research project, supported by NSF, FEMA, and industry, was led by UC San Diego. This research is expected to improve modeling tools, educational programs, and standards and practices in the fields of performance-based building design and construction; design and installation practices, building codes, and standards related to nonstructural components and systems; and post-earthquake fire protection. Additional information about this work is available at http://bncs.ucsd.edu/index.html.

Figure 3–3. UC San Diego tested this full-scale building, outfitted with nonstructural components such as an intensive care unit, a surgery suite, piping, ductwork, fire barriers, and a working elevator, on its NEES shake table. © 2013 Image Courtesy of Tara Hutchinson.

Profiling deep shear wave velocity

Following the Christchurch, New Zealand earthquake, an NSF RAPID award went to the University of Texas at Austin for deep shear wave velocity profiling of the Christchurch area. This work characterized the shear wave velocity (V_s) structure of the sand and gravel deposits deeper than 400 meters beneath Christchurch. This information is critical to support rebuilding decisions in Christchurch, but will also have implications for characterizing deep shear wave velocities in other locations. The researchers also compared two methods of characterizing deep shear wave velocities—large active-source and passive-wavefield surface wave methods—to evaluate the reliability of merging them. The findings can be used in seismically active areas of the United States underlain by deep sedimentary basins, such as Los Angeles and Seattle.

Studying the levees of the Sacramento Delta

The Sacramento/San Joaquin Delta is an inland delta at the western edge of California's Great Central Valley. Fresh water for about half of California flows through the delta. About 1,100 miles of earthen levees were built around swampy islands, starting after the Civil War, to reclaim these lands for farming. The levees are at risk of catastrophic failure (defined as having as many as 50 individual failures at once) from local and regional earthquakes. A failure of this scale would likely

result in salt water from San Francisco Bay contaminating the water in the delta and fouling the water supply for half the population of California.
NSF supported research at the University of California, Los Angeles to measure the seismic response of the peat soil that underlies many of the levees. Using a NEES mobile field shaker (an eccentric mass shaker), researchers simulated the pulsing of a large earthquake on an embankment model of the delta's levees. Analysis of the data will provide the basis for numerical models and estimates of stresses inside embankments. This research will inform decision-making at the state and Federal levels and promote actions to avert a statewide disaster for the delta and the people downstream whose lives depend on it.

Researching deep, slender wide-flange structural steel beam-columns

With support from NIST, the NEHRP Consultants Joint Venture, a partnership of the Applied Technology Council (ATC) and the Consortium of Universities for Research in Earthquake Engineering (CUREE), developed a plan to research critical information about the seismic behavior of deep, slender wide-flange structural steel beam-columns in steel building frames (*Research Plan for the Study of Seismic Behavior and Design of Deep, Slender Wide Flange Structural Beam-Column Members*, NIST GCR 11–917–13). This topic was identified as an area in critical need of study by the American Institute of Steel Construction because some deep, slender columns can be vulnerable to weak-axis and local buckling failure modes. The resulting plan includes a summary of both experimental and analytical research tasks, and is intended to be the first step in the development of nationally accepted guidelines for designing and assessing the seismic performance of deep, slender wide-flange beam-columns in steel frame systems, which are commonly used in building construction.

Objective 3: Advance understanding of the social, behavioral, and economic factors linked to implementing risk reduction and mitigation strategies in the public and private sectors

Supporting social science research on earthquakes

NSF supported a wide variety of social science and multidisciplinary research with relevance to earthquakes. This research covered topics ranging from better understanding human behavior during earthquakes to improving modeling of post-disaster response and recovery. One study used data from cell phones to understand how people's behavior, in terms of their movement and cell phone usage, changes in times of disaster. Another study documented how people behave during and immediately after an earthquake by studying what happened in Japan and New Zealand following their recent large and devastating earthquakes. Residents' behaviors immediately after an earthquake can affect death and injury rates, as well as other disaster impacts, and researchers aim to model these links.

Several studies looked at emergency response issues. One study took a multidisciplinary look at hospital performance during earthquakes, considering the probable damage to facilities, resource allocation and accessibility, hospital worker behavior during an emergency, patient characteristics and how all of these issues interact to affect overall care during a disaster. Another study looked at how cascading disasters, such as the earthquake, tsunami, and nuclear meltdown that affected Japan,

impact the post-disaster humanitarian logistics response and documented lessons from the Japanese event. Another study is looking at how businesses and services that care for deaths, such as funeral homes, coroners, and crematoria, can improve their preparedness for mass casualty events and identifying barriers to preparedness.

Some of the research focuses on community recovery after a disaster, including one study that aims to map out the community recovery process and identify the key societal factors that lead to enhanced recovery. Another study looked at the psychological "sense of community" and how this relates to community resilience and recovery. A third study is looking at the effectiveness of pre-disaster recovery plans in facilitating post-disaster recovery, with particular attention to how the participation of socially vulnerable populations affects this process. All of this research is building toward a richer understanding of how people and societies are affected by and respond to earthquakes.

Focusing future research on the New Zealand and Japan earthquakes

The Earthquake Engineering Research Institute (EERI) convened a workshop with support from NSF to identify themes and directions for research prompted by the 2010 and 2011 New Zealand earthquakes and the 2011 Great East Japan offshore earthquake and tsunami. These events are unique for the research community because of the unprecedented amount of data available and because of their relevance to communities in the United States. NSF supported more than 50 RAPID awards to collect perishable data soon after these events, and these projects have generated large amounts of data on many topics. These topics include geotechnical, structural, and lifelines performance; emergency preparedness, response, and relief; the role of information technology in response and recovery; and tsunami generation, run-up, and impacts on the natural and built environments. The purpose of the workshop was to focus future research, using the enormous amount of data generated by these events, on the topics most needed to promote earthquake-resilient communities.

The workshop participants recommended that future research focus on improved understanding of four key areas:

- The key components of resiliency
- The established and emerging role of information technology in mitigation and response
- The many-dimensioned implications of the Japanese radiological disaster
- The socioeconomic consequences of such catastrophic events

The workshop report includes recommendations on research directions, data collection and management, and use of modeling, computational, and analytic capabilities. The workshop report is available at https://www.eeri.org/wp-content/uploads/JAPAN_NZ_RAPID_Workshop_Final.pdf.

Objective 4: Improve post-earthquake information acquisition and management

Improving the deployment of post-disaster quick response teams

NSF sponsored a workshop to identify best practices for the practical aspects of deploying research teams quickly and effectively to disaster-affected areas to gather perishable data. The workshop provided a forum for information exchange and the development of best-practice recommendations to NSF and the hazards community on how to organize and support reconnaissance teams funded by RAPID awards following a major disaster.

Using real-time GPS to better understand hazards

NSF sponsored a workshop focused on the use of real-time GPS data for hazard applications, to build upon prior efforts undertaken at EarthScope Plate Boundary Observatory GPS stations. The workshop, made possible with American Recovery and Reinvestment Act (ARRA) funding, was organized by UNAVCO, a nonprofit university-governed consortium that facilitates geosciences research using geodesy. More than 80 scientists from the geodesy, seismology, weather, space weather, and hazards communities discussed methods for collecting, processing, and distributing high-rate, real-time continuous GPS data. They also outlined requirements for GPS-based inputs for hazards applications, including earthquake early warning, tsunami warning, and volcano monitoring. This technology could have substantial impacts on the ability to assess natural hazards in near real time, including source characterization for large earthquakes, tsunamis, and volcanic eruptions, directly influencing how science and society prepare for and react to these hazards.

Developing a prototype database for the Chile earthquake

Many U.S. organizations, universities, design firms, and individuals participated in post-earthquake reconnaissance teams after the 2010 Chile earthquake because this earthquake was widely recognized as having potential implications for U.S. seismic design practice. With NIST sponsorship, the NEHRP Consultants Joint Venture used the large amount of data from this earthquake to share critical information about the Chile event and to make a prototype of an eventual NIST disaster and failure events database, using NEEShub technology (the NEES cyberinfrastructure system). The beta version of this database was shared with a panel of researchers and practitioners, and the next generation database is currently being developed.

Hazards SEES: supporting interdisciplinary research in hazards and disasters, an initiative spanning objectives 1–4

Earthquakes can have complex consequences, and fully addressing them requires that scientists, engineers, and social scientists combine their knowledge. Recognizing this, NSF launched the Hazards SEES program (program solicitation 12–610) to promote well-integrated, interdisciplinary research in hazards-related science and engineering. Hazards SEES will make investments in strongly interdisciplinary research aimed at reducing the impacts of natural hazards and technological hazards linked to natural phenomena, enhancing the safety of society, and contributing to sustainability. This multi-directorate program seeks to advance understanding of the fundamental

processes associated with natural hazards and technological hazards linked to natural phenomena, and their interactions; better understand the causes, interdependencies, impacts, and cumulative effects of these hazards on individuals, the natural and built environments, and society; improve capabilities to forecast or predict hazards and mitigate their effects; and enhance the capacity to respond to and recover from disasters. Hazards SEES research will also help train a new generation of scientists for interdisciplinary hazards and disaster research.

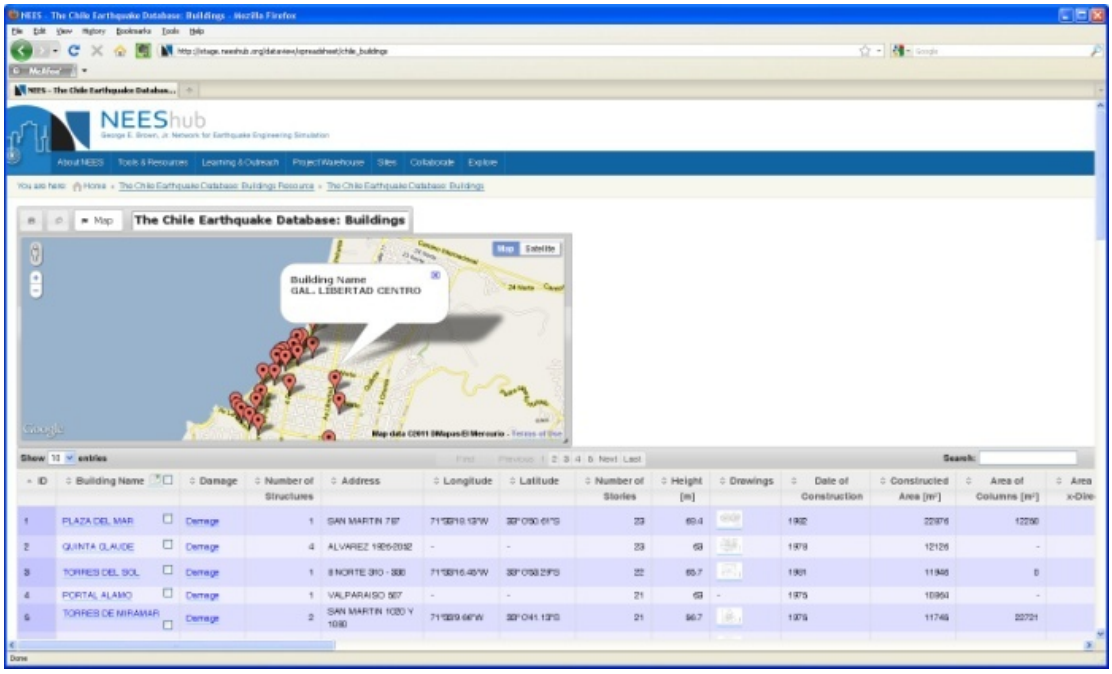


Figure 3–4. A screen from the beta version of the prototype NIST disaster and failure events database, populated with data from the 2010 Chile earthquake, using NEEShub technology. Image courtesy of NIST.

3.2 Goal B: Develop Cost-Effective Measures to Reduce Earthquake Impacts on Individuals, the Built Environment, and Society at Large

NEHRP activities under Goal B are designed to develop practical and cost-effective methods and measures for earthquake risk assessment and mitigation that build upon the research results obtained under Goal A. Goal B is directly linked to the congressionally defined NEHRP program activity "Develop effective measures for earthquake hazards reduction."

Objective 5: Assess earthquake hazards for research and practical application

Completing the Evansville Area Earthquake Hazards Mapping Project

The Evansville (IN) Area Earthquake Hazards Mapping Project (EAEHMP), a collaborative effort among USGS and several regional partners, was completed. Partners included Purdue University, the Center for Earthquake Research and Information at the University of Memphis, the state

geological surveys of Kentucky, Illinois, and Indiana, the Southwest Indiana Disaster Resistant Community Corporation, and the Central U.S. Earthquake Consortium (CUSEC) state geologists.

Finished products include three types of hazard maps for the Evansville area: probabilistic seismic-hazard maps portraying expected ground motion with a given probability of occurring within a given period of time; scenario ground-shaking maps showing expected shaking from two specific scenario earthquakes, a M6.8 Wabash Valley event and a M7.7 New Madrid event; and liquefaction-potential maps showing how likely strong ground shaking from the scenario earthquakes is to produce liquefaction. These maps complement the USGS National Seismic Hazard Maps, but are more detailed regionally, accounting for surficial geology, soil thickness, and soil stiffness, which greatly affect ground shaking.

A public workshop was held to release the Evansville urban hazard maps on the day of the 2012 Central U.S. ShakeOut earthquake-response drill. The workshop was well attended by a diverse cross section of the community, from city officials and county commissioners to professionals in the banking and insurance industries, emergency response personnel, builders, and engineers. Additional information about the EAEHMP products can be found on the project website, http://earthquake.usgs.gov/regional/ceus/urban_map/evansville/.

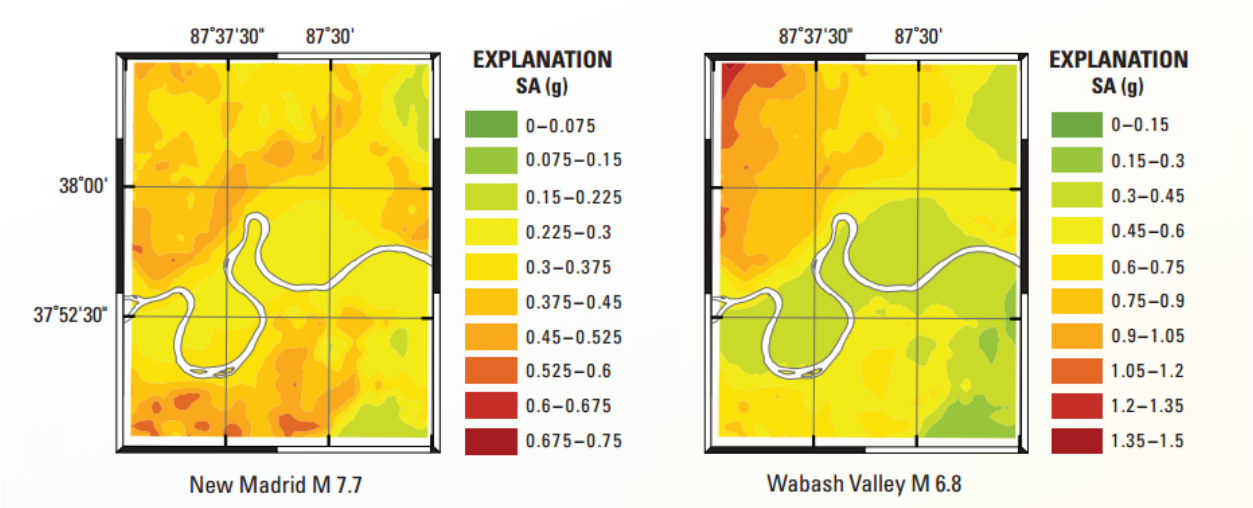


Figure 3–5. Scenario-based maximum ground motion maps for the Evansville, IN, area. These maps show the expected maximum spectral accelerations at a period of 0.2 seconds for two scenarios: a M7.7 New Madrid earthquake and a M6.8 Wabash Valley earthquake. (SA stands for spectral acceleration; g stands for the force of gravity.) Image courtesy of USGS.

Developing seismic hazard maps for American Samoa and Guam

USGS scientists from the National Seismic Hazard Mapping Project developed seismic hazard maps for the Guam/Northern Mariana Islands and American Samoa regions. The maps consider new earthquake source and ground motion models that are specific to these regions, and apply the same methodologies that are used in constructing the conterminous U.S. hazard maps. Open workshops were held in Berkeley, CA; Guam; Saipan; and American Samoa to discuss input models and obtain

consensus within the technical and local science and engineering communities on the maps' usefulness for design. It is expected that earthquake ground motion provisions for building codes derived from these hazard maps will be considered for adoption in the *International Building Code*, the *NEHRP Recommended Seismic Provisions for New Buildings and Other Structures*, and the U.S. Department of Defense *Unified Facilities Criteria*.

Clarifying how to select, generate, and scale ground motions for analyses

The NEHRP Consultants Joint Venture, sponsored by NIST, completed the report *Selecting and Scaling Earthquake Ground Motions for Performing Response-History Analysis* (NIST GCR 11–917–15). The report presents guidance for selecting, generating, and scaling earthquake ground motions to use in response history analyses, which are needed for performance-based seismic engineering. Seismic provisions in current model building codes and standards include rules for designing structures using nonlinear response-history analysis that are largely based on recommendations for analysis of seismically isolated structures from more than 20 years ago. Prior to this report, there was no consensus in the earthquake engineering community on how to appropriately select and scale earthquake ground motions for code-based design and seismic performance assessments of buildings using nonlinear response-history analysis.

Improving seismic attenuation models for hazard assessment

Maps of seismic hazard in the United States depend upon simple equations derived from observed earthquake motions that predict the expected maximum ground motion on a given type of soil at a given distance from a hypothetical earthquake epicenter. These equations are often called *attenuation relations*, as they describe the way earthquake ground shaking diminishes with distance. USGS scientists have participated heavily in the Next Generation Attenuation (NGA)-West 2 project. The NGA-West 2 project, managed by the Pacific Earthquake Engineering Research Center of the University of California, Berkeley, is funded by the California Earthquake Authority, which will use the results of the study to help determine earthquake insurance rates in California; the California Department of Transportation; and the Pacific Gas & Electric Company. The new attenuation relations will become standards for most hazard-estimation uses in the West, and will influence future building codes and the design of many special-purpose structures. In addition to providing improved attenuation relations, the NGA-West 2 project has assembled a database of worldwide earthquake ground motion recordings relevant to the Western United States, which will be made available to the public at the completion of the project. USGS scientists are also working with colleagues from Western University, Canada, and the University of California, Los Angeles, to study attenuation relationships for eastern North America; and with colleagues from the California Department of Transportation to develop models of directivity, which is the focusing and amplification of ground motions in certain areas around an earthquake epicenter.

Providing 3-D tectonic models online: Slab1.0

The USGS National Earthquake Information Center completed and released Slab1.0, a new three-dimensional model of the geometries of global subduction zones. Using data from several global earthquake catalogs, bathymetric data sets, and active-source seismic data gathered from geoscience

literature, this model describes the detailed three-dimensional form of over 85 percent of the world's subduction zones by area—from their trenches, through their shallow seismogenic zone, to their deepest seismically active extent in the Earth's mantle. The model already has seen extensive use in a variety of applications and literature, from studies of seismic hazard, tsunami modeling and propagation, and earthquake source analyses, to modeling mantle convection. Slab1.0 will also be incorporated into the forthcoming Global Active Fault and Seismic Source Database, under development through the Global Earthquake Model initiative. For more information, see http://earthquake.usgs.gov/research/data/slab/.

Objective 6: Develop advanced loss estimation and risk assessment tools

Providing guidance on the seismic evaluation of wood-frame structures

FEMA published *Simplified Seismic Assessment of Detached, Single-Family, Wood-Frame Dwellings* (FEMA P–50) and *Seismic Retrofit Guidelines for Detached, Single-Family, Wood-Frame Dwellings* (FEMA P–50–1). These publications are based on ATC–50, which was developed after the 1994 Northridge earthquake for the City of Los Angeles, but they have been expanded for use in high-seismic areas nationwide. The FEMA P–50 system assigns a rating score based on a number of building characteristics, including foundation, framing and configuration, and general condition assessment, and identifies items that can be retrofitted to improve scoring.

FEMA also completed *Seismic Evaluation and Retrofit of Multi-Unit Wood-Frame Buildings with Weak First Stories* (FEMA P–807). This publication, which was developed in coordination with the San Francisco Community Action Plan for Seismic Safety project, targets "Marina District" and Northridge style weak-story, multi-unit, wood-frame residential structures and presents a new technique that can be used to more effectively retrofit these structures. FEMA P–807 includes a calculation tool to account for the strength of all walls in the building, including nonstructural walls. The publication is now available on the NEHRP, ATC, and NEES websites, and is available in a combined paper and CD-ROM version from the FEMA Publications Warehouse.

Objective 7: Develop tools that improve the seismic performance of buildings and other structures

Advancing state-of-the-art performance-based seismic design

FEMA, through a contract with ATC, completed the development of *Seismic Performance Assessment of Buildings: Volume 1—Methodology* (FEMA P–58–1) and the accompanying Performance Assessment Calculation Tool (PACT, FEMA P–58–3). Two additional products in this series are *Seismic Performance Assessment of Buildings: Volume 2—Implementation Guide* (FEMA P–58–2) and a new CD that includes assessment volumes 1 and 2 and the PACT. Published in September 2012, this performance assessment methodology allows a designer to assess the seismic performance of proposed or existing individual buildings in future earthquakes. These products represent the first phase of the development of performance-based seismic design (PBSD) guidelines for new and existing buildings. The ultimate goal is to be able to evaluate how a building is likely to perform in a

given earthquake, considering uncertainties inherent in both the potential hazard and actual building response. PBSD guidelines will permit the design of new buildings or upgrading of existing buildings with a realistic understanding of the risk of casualties, occupancy interruption, and economic loss that may occur as a result of future earthquakes.

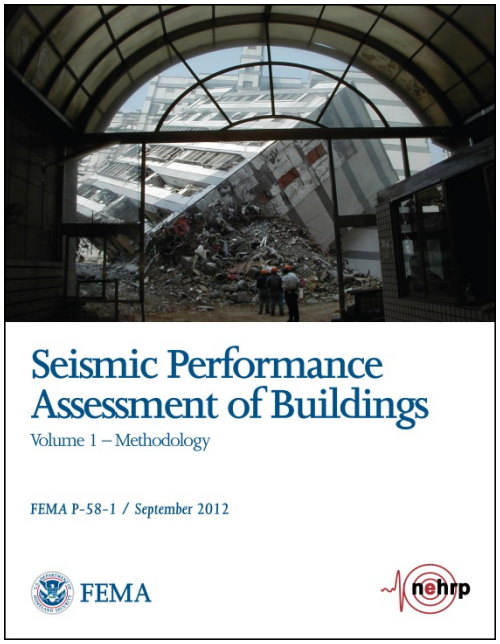


Figure 3–6. FEMA's P–58 publication provides a methodology for engineers to use to assess the seismic performance of proposed or existing individual buildings in future earthquakes. Cover photo © 1999 Image Courtesy of Farzad Naeim, John A. Martin and Associates.

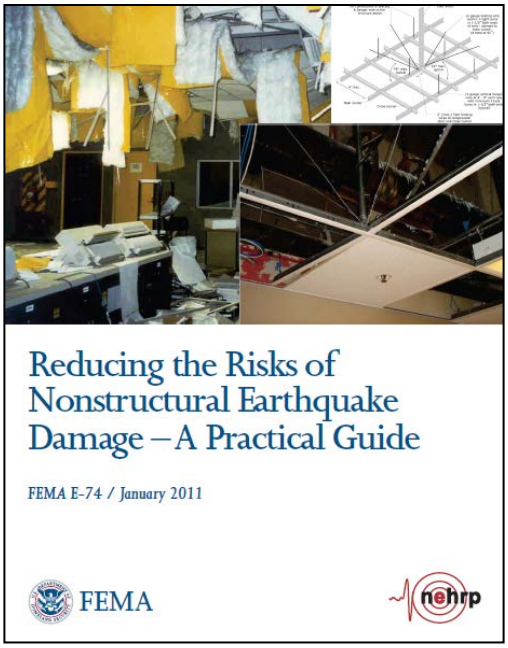
Reducing the risks of nonstructural earthquake damage

During recent earthquakes in Chile, New Zealand, Japan, and Virginia, and earlier earthquakes in California, Washington, and other parts of the United States, nonstructural failures accounted for the majority of damage and injuries. Businesses, schools, hospitals, and other organizations had to spend significant time and money for clean-up and repair necessitated by nonstructural failures. The failure of nonstructural components, which include architectural, mechanical, electrical, and plumbing systems, as well as furniture, fixtures, equipment, and other building contents, also can impede safe evacuation, delay rescue, and cause additional hazards resulting in serious life-safety issues.

Reducing the Risks of Nonstructural Earthquake Damage (FEMA E–74) is an electronic publication posted on the FEMA website. This report describes sources and types of nonstructural earthquake damage and presents effective methods and guidance that can be used by individuals and organizations—before the next earthquake—to minimize future injuries and property losses from nonstructural risks. FEMA developed updates for FEMA E–74 on nonstructural damage seen in Chile (e.g., the failure of more than 70 percent of elevators), New Zealand (e.g., the collapse of precast concrete emergency exit stairways in 12 buildings), and Japan (e.g., the failure of suspended ceiling systems). These updates have been finalized and are being added to the publication on the FEMA website. Webinar training on FEMA E–74 was conducted for thousands of people across the United States.

The Structural Engineers Association of California recognized the developers of FEMA E–74 (FEMA, ATC, and Estructure) with its 2012 Structural Engineering Award of Excellence at its annual conference in Santa Fe, NM.

Figure 3–7. Nonstructural damage has caused the majority of injuries and losses in many recent earthquakes. FEMA updated its E–74 publication to incorporate lessons learned from recent earthquakes and trained thousands in techniques to reduce nonstructural damage. Cover photos © 2001 Images Courtesy of Maryann Phipps, Estructure, and Eduardo Fierro, BFP Engineers, Inc.



Testing new technologies with the NEES facilities

The NEES laboratories conducted a wide variety of tests to examine new approaches for improving building resistance to earthquake shaking. A partial list of these programs appears below:

- Testing resilient self-centering steel plate shear walls—these newly developed structural elements confine yielding and damage to sacrificial and easily replaced infill plates and re-center building frames using stored elasticity in pre-tensioned boundary frames. This can reduce downtime and repair costs in buildings following earthquakes and contribute to reducing overall earthquake losses. Tests on these walls were conducted as part of ongoing research.
- Testing smart devices—the Next-Generation Adaptive Seismic Protection System, an innovative adaptive seismic protection system that combines fluid viscous dampers and a new device called the Negative Stiffness Device, was tested in a three-story building on the shake table at the University at Buffalo NEES laboratory. These systems significantly reduce the amount of energy transmitted to a structure so that it suffers little or no damage and remains serviceable even after a strong earthquake.
- Testing an innovative pipe-climbing robot designed for post-earthquake damage Inspections—researchers at San Jose State University developed a unique robotic system that can climb 2- to 6-inch-diameter vertical pipes to perform pipe inspection tasks after an earthquake. The system contains climbing and rotating mechanisms and sensors to detect

both interior and exterior defects in piping. Currently, pipe inspection after an earthquake is performed manually, which is less reliable and accurate and is limited by accessibility, visibility, lighting conditions, and risky environments.

- Testing bacteria for stabilizing liquefiable soils: a sustainable technology—researchers at the NEES Geotechnical Centrifuge at the University of California, Davis developed a new method that uses a natural biological process to stabilize liquefaction-prone sandy soils that support structures. A series of centrifuge tests at the facility assessed the extent to which resistance to liquefaction is improved by a particular bio-mediated method, microbiologically induced calcite precipitation. Over $7 billion of ground improvement work to support new or existing infrastructure occurs each year. Most current technologies are energy and cement intensive, resulting in a relatively large carbon footprint. The newly developed technology uses naturally existing bacteria and only requires the addition of calcium and nutrients.

Monitoring a base-isolated building in New Zealand

NSF supported Duke University through a RAPID grant to measure the long-term seismic responses of the base-isolated Christchurch, New Zealand, Women's Hospital. This hospital, completed in March 2005, is the only base-isolated building on New Zealand's South Island. It experienced only minor damage during the 2010 earthquake and subsequent aftershocks, but was not instrumented at the time of these earthquakes. The NSF award supported nine networked accelerometers and three displacement sensors, installed at three levels within the structure. These devices will permit remote monitoring and rapid data processing of how the building responds during aftershocks. High-fidelity measurements from this building during aftershocks will be combined with detailed computer simulations of the structure and its base-isolation system, foundation, and supporting soft soil. This information will be used to research the relative effects of soil-foundation-structure interactions with liquefying soil, for interactions between adjacent buildings and for interactions across the isolation interface. This effort will provide information to improve the design of new base-isolated structures on soft soils in seismic regions worldwide.

Objective 8: Develop tools that improve the seismic performance of critical infrastructure

Expanding the use of ShakeCast—rapid assessment of earthquake damage potential

Damage to critical infrastructure due to strong shaking during large earthquakes is inevitable. However, the consequences of such damage can be mitigated with proper planning and improved situational awareness during the early post-event period. When earthquakes occur, USGS ShakeMaps portray the extent of potentially damaging shaking. The ShakeCast system is a freely available, post-earthquake situational awareness application that automatically retrieves earthquake shaking data from the ShakeMap, compares intensity measures against users' facilities, sends notifications of potential damage to responsible parties, and generates facility damage assessment maps and other web-based products for emergency managers and responders (see http://earthquake.usgs.gov/research/software/shakecast/). Use of ShakeCast has continued to grow across a broad array of Federal, state, county, and private-sector users, as described below.

ShakeCast is useful for lifeline operations and was originally developed with the input of the California Department of Transportation. New utility users include the Los Angeles County Department of Public Works, which uses ShakeCast to track the structural performance of over 5,000 county facilities, including dams, water tanks, and buildings. Nearly 150 personnel within the department now receive alerts via ShakeCast within minutes of an earthquake. The Port of Long Beach is also a new user. If a major earthquake that meets specific criteria occurs, ShakeCast sends an e-mail alert to activate the port's Post-Earthquake Infrastructure Inspections Standard Operating Procedure and notifies many of the port's business continuity teams, which are responsible for performing rapid inspections and implementing workaround strategies for impacted infrastructure and utilities to ensure that the port remains open for business.

Among new critical-facility users is the International Atomic Energy Agency, which partnered with USGS and the U.S. Nuclear Regulatory Commission to develop a tool used to monitor peak ground acceleration at nuclear power plants across the globe. With this Nuclear ShakeCast tool in place, nuclear facilities can be monitored remotely from the International Seismic Safety Centre in Vienna, Austria, to enforce operational procedures and safe-shutdown exceedances.

In the commercial sector, Walmart, Target, and Degenkolb Engineers have now implemented ShakeCast. Walmart and Target use the system to monitor earthquake shaking levels at their facilities (including all retail stores, distribution centers, and corporate facilities) and improve situational awareness. ShakeCast allows Walmart, for example, to prioritize its emergency response and aid distribution without waiting for on-site inspections of impacted facilities. Degenkolb Engineers incorporates ShakeCast into its alert service, which provides participating clients with hosting, maintenance, configuration, and support for a dedicated Degenkolb ShakeCast server. In return, Degenkolb clients receive rapid structural damage estimates that can be used for evacuation protocols and prioritized building inspections.

Studying how underground systems perform in earthquakes

NSF supported a number of researchers studying the effects of soil-structure interaction during earthquake shaking. NSF provided a RAPID award to the University of California, Irvine to study the impact of earthquakes on underground systems, such as subways and underground malls. This project modeled elevators and an underground shopping center using two vertical shafts connected with a cut and cover tunnel, and a subway system using two horizontal shafts. The project involved active collaboration among Japanese and American researchers. Using the E-Defense shake table in Miki, Japan, this experiment provided a unique opportunity to study local and global behavior of tunnel-shaft systems installed in a laminar soil container under a series of two-dimensional motions.

3.3 Goal C: Improve the Earthquake Resilience of Communities Nationwide

Through activities supported under Goal C, NEHRP agencies work to apply research results developed under Goal A and risk-reduction methodologies developed under Goal B to practical measures that will increase public safety and reduce losses in future earthquakes. Work under this

goal includes the monitoring and reporting of seismic activity worldwide. Goal C is directly related to the congressionally defined NEHRP program activity "Promote the adoption of earthquake hazard reduction measures by Federal, state, and local governments, national standards and model code organizations, architects and engineers, building owners, and others with a role in planning and constructing buildings, structures, and lifelines."

Objective 9: Improve the accuracy, timeliness, and content of earthquake information products

Testing an earthquake early warning system

An earthquake early warning system can detect the occurrence of an earthquake near its source and immediately broadcast a warning of imminent strong ground shaking to more distant areas. A warning issued a few tens of seconds in advance of shaking could allow schools, hospitals, critical facilities, lifeline operators, and the general public to take precautionary actions. In January 2012, a demonstration version of the ShakeAlert earthquake early warning system began sending real-time notifications to selected test users in California. These users include emergency responders, utilities, rail companies, and other businesses. The system was developed with USGS grant support by the University of California (UC) Berkeley, the California Institute of Technology (Caltech), and SCEC. The Gordon and Betty Moore Foundation has awarded $6.5 million over 3 years to UC Berkeley, Caltech, the University of Washington, and USGS to do further research, with the goal of creating a prototype warning system for the west coast of the United States. The ShakeAlert system uses real-time ground motion data from USGS Advanced National Seismic System (ANSS) network stations.

Improving rapid magnitude estimates: W-Phase Moment Tensor Inversion

The W-phase is a seismic wave characterized by very long period vibrations (approximately 100 seconds). Because it starts to arrive at a seismic station very early in the sequence of seismic waves from an earthquake, it is useful in the rapid interpretation of the size and nature of the earthquake source. Moment-tensor inversion is an analytical means used to determine the strength and orientation of the forces acting at the earthquake source. W-phase moment tensor inversion has been used at the USGS National Earthquake Information Center (NEIC) since 2009 to provide accurate estimated magnitudes for moderate-to-large distant earthquakes within an hour after an event occurs. In collaboration with colleagues at the University of Strasbourg in France and Caltech, the NEIC has adapted this procedure for application to less distant, regional earthquakes, enabling reliable estimates of magnitude within 10 minutes of an earthquake where regional data coverage is dense. This means rapid and accurate magnitudes can be determined for most U.S. earthquakes as well as for events in much of Central and South America, the Caribbean, Japan, and Europe. New data for the application of this technique will be available through the continued expansion of the ANSS network, the conversion of temporary stations deployed by the Incorporated Research Institutions for Seismology (IRIS) to permanent sites in the Eastern United States, improvements in collaborations with international network operators, and further upgrades to the Global Seismographic Network (GSN) stations.

Using Twitter to inform and monitor for earthquakes

The USGS NEIC has launched Tweet Earthquake Dispatch, which distributes earthquake alerts through the social media site Twitter via two accounts: @USGSted and @USGSBigQuakes (http://earthquake.usgs.gov/earthquakes/ted/). Both accounts distribute alerts for events of M5.5 and above; the former also provides information related to tweets from the region surrounding the epicenter of the earthquake, in addition to seismically derived content. By the end of FY 2012, @USGSted had over 30,000 followers and @USGSBigQuakes had about 10,000 followers.

The NEIC has also established Twitter event detection for automated identification of messages referring to earthquakes using Twitter, and for the distribution of e-mail alerts to an internal user group. While the Twitter earthquake messages do not cover all seismic events located by the NEIC, they often provide a "heads up" before events are detected through conventional seismic means. This is because seismic waves travel through the Earth at speeds measured in kilometers per second, while electronic messages travel at nearly the speed of light. Social media users who feel and tweet about earthquakes can give NEIC responders a situational awareness of the potential impact of an earthquake.

Modeling real-time tectonics

For several years, the USGS NEIC has modeled fault slip distributions of large earthquakes in near-real time, in collaboration with the University of California, Santa Barbara. These models have been extensively used by the seismologic community. They also benefit other earthquake response products at the NEIC, including PAGER, a system that provides fatality and economic loss estimates following significant earthquakes worldwide. The NEIC has also adopted new rapid approaches for modeling the first-order characteristics of an earthquake rupture. The center began implementation of a second finite fault modeling approach in collaboration with the Universidad Nacional Autónoma de México, aimed at rapidly estimating the first-order characteristics of an earthquake rupture before they can be modeled in more detail with existing algorithms. These new approaches should facilitate the estimation and publication of rupture models within 30 minutes to 60 minutes of future large earthquakes. These models are useful in assessing earthquake impacts and aftershock potential.

Monitoring geodetic information for earthquake response and research

USGS uses GPS to observe the slow buildup of crustal strain between large earthquakes, sudden strain release associated with large earthquakes, and accelerated strain that may occur after such events. USGS operates eight permanent, continuously operating GPS stations in the San Francisco Bay Area and 104 stations in southern California, 9 of which are co-located with seismic stations from the Southern California Seismic Network. About 80 percent of the stations now operate in real time, producing instantaneous data useful for earthquake response and, possibly, for earthquake early warning. Through its external research program, USGS supports five GPS networks—in northern California, the Pacific Northwest, Nevada, Utah, and the Central United States (New Madrid Seismic Zone). Each day, USGS processes 24 hours of data from all of these stations, plus many operated by the Plate Boundary Observatory (http://earthquake.usgs.gov/monitoring/gps/).

Efforts are under way to develop real-time data processing techniques that will make the deformation measurements from all sites immediately available. Further co-locations of geodetic and seismic sensors are planned. In addition, USGS collects and processes data at about 1,300 GPS campaign sites (sites occupied with GPS receivers only every year or so) throughout the Western United States.

The August 2012 Brawley, CA, earthquake provides a recent example of the use of this system. The earthquake swarm produced more than 600 aftershocks, the three largest with M4.9, M5.3, and M5.4. The swarm produced surface displacements at nearby GPS stations. Ground surface deformations from GPS sites and from high-resolution interferometric synthetic aperture radar (InSAR) images were used to guide field reconnaissance, enabling geologists to map surface fractures that they might otherwise have missed.

Pacific Northwest Seismic Network (PNSN)

The PNSN is supported by USGS through a cooperative agreement as part of ANSS. In addition to monitoring and reporting on seismic activity in the region, other significant activities of the PNSN are reported below:

- Installing a liquefaction array in Seattle: Liquefaction occurs when certain, usually saturated, soils and sediments lose their bearing strength during earthquake shaking; this can cause severe damage to or the collapse of structures built on such soils. Installation of a geotechnical liquefaction array was completed at a site south of downtown Seattle. The array consists of three tri-axial borehole accelerometers and six borehole pressure transducers in a linear array about 30 meters long. There is also a tri-axial accelerometer at the surface. The data are telemetered continuously to both the PNSN data center at the University of Washington and the NEES data center at the University of California, Santa Barbara. The array site has experienced liquefaction in previous Seattle area earthquakes. This array will provide useful information about future liquefaction events. The site's proximity to a major railroad facility also provides useful data concerning ground water pressure response to man-made disturbances.
- Cooperative seismic monitoring improvements with the Bonneville Power Administration: A multiyear project is under way to transfer seismic data channels from the Bonneville Power Administration's analog regional microwave communications system to its new digital telecommunications system. The transfer process began in April 2012 after a long period of preparation. Currently, 21 of 34 channels have been transferred.

Objective 10: Develop comprehensive earthquake risk scenarios and risk assessments

Developing earthquake scenarios for New England

FEMA Region I staff worked with FEMA Region VIII, USGS, FEMA headquarters, Weston Observatory, the Northeast States Emergency Consortium (NESEC), the Vermont State Geologist, and the New England States to complete the *HAZUS Analysis of Eleven Scenario Earthquakes in New England* report. Region I staff presented the report at a NESEC directors meeting and distributed it

to state and local stakeholders. Maine contacted Region I about using one of the scenarios for an exercise in the summer of 2013. Maine also is using information from the report for the update to its hazard mitigation plan, and FEMA Region I is using the information for its catastrophic plan update.

Objective 11: Support development of seismic standards and building codes and advocate their adoption and enforcement

Developing design examples for the NEHRP Recommended Seismic Provisions

In 2009, FEMA developed an updated edition of the *NEHRP Recommended Seismic Provisions for New Buildings and Other Structures* (FEMA P–750) to support development of seismic standards and building codes and advocate for their adoption and enforcement. This was the seventh update of this key resource document, which was originally published in 1985. In 2012, FEMA completed the supporting document, *2009 NEHRP Recommended Seismic Provisions: Design Examples* (FEMA P–751CD). The design examples in this publication provide detailed guidance on application of the latest NEHRP recommended seismic provisions. They serve as an educational tool for students, college professors, and practicing engineers. This publication is available in the online FEMA Library and through the FEMA Publications Warehouse. In addition, the *2009 NEHRP Recommended Seismic Provisions: Training Materials* (FEMA P-752CD) underwent extensive revision and was completed in August 2013.

Tracking building code adoption

A key strategy that communities can implement to reduce seismic risk is to adopt and implement national model building codes that include earthquake-resistant provisions. To track adoption of earthquake-resistant code provisions by communities, FEMA, with contractor support, maintains the Building Code Adoption Tracking System. This system uses the Building Code Effectiveness Grading Schedule (BCEGS) from the Insurance Services Office (ISO) and other public information to monitor building code adoption and implementation by jurisdictions with high or very high seismic hazard. This effort continued in 2012, at the end of which 48 percent of the BCEGS communities with high or very high seismic hazard had adopted codes with earthquake-resistant provisions.

Learning about codes from the 2010 Chile earthquake

The NEHRP Consultants Joint Venture, supported by NIST, completed a report comparing Chilean and U.S. building codes over the past three decades: *Comparison of U.S. and Chilean Building Code Requirements and Seismic Design Practice 1985–2010* (NIST GCR 12–917–18). This work is part of a series of investigations into the performance of engineered construction during the 2010 Maule earthquake in Chile. The report provides an understanding of the similarities and differences between U.S. and Chilean seismic design codes and practices so that meaningful conclusions can be drawn from the observed performance of buildings in Chile. Chilean codes are roughly based on U.S. codes. The report summarizes the effects of the 2010 earthquake, contrasts Chilean and U.S.

codes and seismic design practices from 1985 to 2010, and presents a comparative design study. This will allow seismic-resistant construction to be improved in the United States.

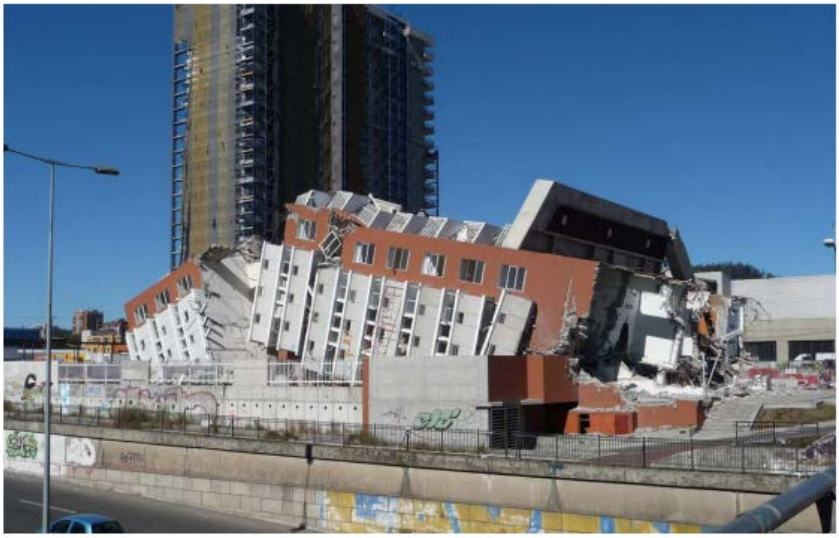


Figure 3–8. Collapse of the Alto Rio building in Concepción, Chile, in the 2010 Maule earthquake. A new report compares U.S. and Chilean design and construction practices so that U.S. engineers can learn from collapses such as this. Image courtesy of FEMA.

Updating guidelines on vertical evacuation from tsunamis

FEMA and the ATC updated *Guidelines for Design of Structures for Vertical Evacuation from Tsunamis* (FEMA P–646). The second edition of this publication incorporates observations and lessons learned from the March 2011 Great East Japan Earthquake, revises the way debris impact is addressed, and provides additional explanation of the definition of tsunami elevation as it relates to run-up elevation used in tsunami force equations.

FEMA Region X funded the development of a video by the FEMA Strategic Alliance for Risk Reduction team to better communicate the FEMA P–646 guidelines to the public. FEMA Region X staff also worked on a tsunami model for HAZUS–MH, in collaboration with the National Oceanic and Atmospheric Administration (NOAA).

Objective 12: Promote the implementation of earthquake-resilient measures in professional practice and in private and public policies

Inventorying URM buildings in Salt Lake City

FEMA Region VIII, the Utah Seismic Safety Commission, and other partners completed the inventory and assessment of approximately 3,000 unreinforced masonry (URM) buildings in Salt Lake City. URM buildings have been responsible for a large portion of severe injuries and deaths in earthquakes worldwide. The inventory has helped to identify mitigation priorities. Project results were made available for the Great Utah ShakeOut in Salt Lake City on April 17, 2012. FEMA's

planned update to *Designing for Earthquakes: A Manual for Architects* (FEMA 454) will incorporate the results from this project.

Helping businesses to become QuakeSmart

FEMA created the QuakeSmart program to help local businesses mitigate earthquake losses and get back up and running as quickly as possible after a disaster. A cornerstone of the program is FEMA's recognition that partnerships are key to raising awareness and ensuring that businesses take action to become "QuakeSmart." In 2011, FEMA released the *QuakeSmart Toolkit* (FEMA P–811CD), a CD-based package of guidance and user-friendly, interactive tools that help businesses reduce the potential for injuries, damage, and financial losses from earthquakes.

FEMA, in partnership with the Federal Alliance for Safe Homes (FLASH), launched a nationwide campaign to put the *QuakeSmart Toolkit,* accompanied by outreach materials, into the hands of as many small businesses as possible. FEMA and FLASH determined that the most cost-effective way to reach the largest number of small businesses would be through targeted outreach to umbrella associations, such as state societies of association executives and associations serving grocers, restaurants, the lodging industry, chambers of commerce, child care providers, small private schools, and museums, among others. Associations have started to market the *QuakeSmart Toolkit* to their small business members. FLASH also plans a pilot program with state fire marshals to distribute the *QuakeSmart Toolkit* to small businesses during their annual fire inspections.

Updates to ROVER, end-to-end software for managing seismic risk

The Rapid Observation of Vulnerability and Estimation of Risk (ROVER) software, available from FEMA online and on CD-ROM, automates two international, standard, paper-based methodologies: *Rapid Visual Screening of Buildings for Potential Seismic Hazards* (FEMA 154) and *Post-earthquake Safety Evaluation of Buildings* (ATC–20). With the automation provided by ROVER, building inspectors no longer need to juggle papers, clipboard, and camera, and managers no longer need to transcribe paper forms. ROVER also shares data with two other tools to manage seismic risk: FEMA's HAZUS–MH loss-estimation software and the USGS ShakeCast system.

The ROVER Server now operates as an online service for ROVER smartphone clients and as a website for direct access by any web browser. The website service has been optimized for the small screens found on smartphones or Internet-connected tablets. An updated ROVER service pack is planned.

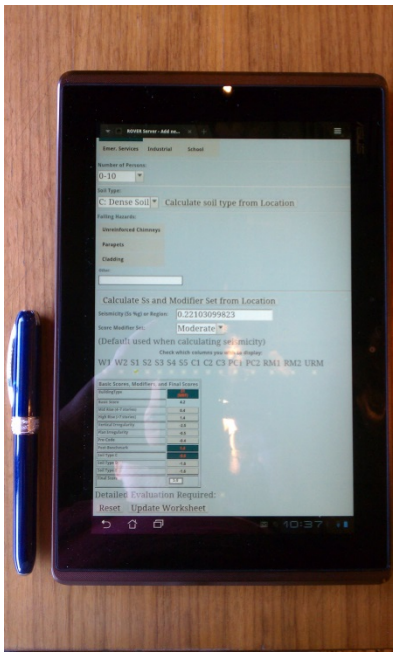


Figure 3–9. A tablet device using the ROVER software, which allows post-earthquake building inspections and pre-earthquake risk assessments to go paperless. © 2011 Image Courtesy of Keith Porter.

NEHRP Tech Brief on mat foundations

NEHRP released another volume in its series of "Tech Briefs," which are concise publications designed to help transfer research results into practice: *Seismic Design of Reinforced Concrete Mat Foundations: A Guide for Practicing Engineers* (NIST GCR 12–917–22). This document synthesizes model code requirements and the latest engineering techniques into clear and concise design and construction guidance on the seismic design of reinforced concrete mat foundations. This type of publication, aimed at practitioners, is important because the technical literature on engineering advances is too voluminous and technically difficult for most practicing professionals to examine or evaluate. In addition, lack of familiarity inhibits adoption of new engineering technologies and, in the absence of practitioner-directed guidance, the quality of engineering practice can vary significantly from one office to another.

Figure 3–10. A newly published NIST Tech Brief presents advice for practicing engineers on designing mat foundations, such as this one under construction. © 2009 Image Courtesy of Magnusson Klemencic Associates.

Training through the National Earthquake Technical Assistance Program

Through the National Earthquake Technical Assistance Program (NETAP), FEMA headquarters and all of the FEMA Regional Offices support the development of training curricula on earthquake mitigation topics and provide courses for state, territorial, tribal, and local officials and businesses throughout the United States.

Demand for NETAP training remains high. Training includes *Procedures for Post-earthquake Safety Evaluation of Buildings* (ATC–20); *Rapid Visual Screening of Buildings for Potential Seismic Hazards* (FEMA 154); *Earthquake Hazard Mitigation for Hospitals* (FEMA P–767); and *Reducing the Risks of Nonstructural Earthquake Damage* (FEMA E–74). Through these and other courses, FEMA has been able to increase state and local knowledge of earthquake mitigation, which in turn supports the effective implementation of local NEHRP-funded projects.

Updating the directory of FEMA earthquake partners

FEMA updated and published its *Directory of FEMA Earthquake Partners*, an online resource available through the FEMA Library. The directory supports FEMA's NEHRP-related partnerships by providing contact information for more than 300 organizations and individuals involved in earthquake mitigation.

Objective 13: Increase public awareness of earthquake hazards and risks

ShakeOut!

ShakeOut events are the largest earthquake preparedness drills in U.S. history. They began in California in 2008, originated by the Earthquake Country Alliance for California, and have now spread to communities worldwide, involving millions of people. October 2011 ShakeOut drills involved over 10 million people in Arizona, California, Guam, Idaho, Nevada, and Oregon, as well as British Columbia. The second Central United States ShakeOut, in February 2012, involved more than 2.4 million participants in nine states (Alabama, Arkansas, Illinois, Indiana, Kentucky, Mississippi, Missouri, Oklahoma, and Tennessee). The first Japanese ShakeOut was held in March 2012, coinciding with the anniversary of the devastating 2011 Great East Japan Earthquake.

ShakeOut drills help people in homes, schools, and organizations improve preparedness and practice how to be safe during earthquakes, increasing earthquake preparedness by exposing participants to consistent and frequent information about what to do—information delivered in many forms and from many sources. ShakeOut activities also provide participants with an opportunity to see others getting prepared, and to talk about preparedness with their family, friends, and coworkers. USGS, in cooperation with the NSF- and USGS-funded Southern California Earthquake Center (SCEC), has developed scenario earthquakes for ShakeOut events and provided multimedia materials for use in the exercises. FEMA provided partial financial support for these activities, as well as assistance from staff located in the agency's regional offices. More information is available at www.shakeout.org.

Developing posters showing the regional seismicity of the Earth

The USGS NEIC developed posters summarizing regional tectonics of major active subduction margins worldwide. These regional summaries provide focused subsets of the *Global Seismicity of the Earth* poster. They serve as an evolving and expanding series explaining the tectonics and historical seismicity of major plate boundaries in more detail than is possible on a global scale. These regional summaries are also used to provide rapid tectonic context for new earthquakes occurring in the same regions, as their event pages are produced and posted to the Earthquake Hazards Program website. For more information, see http://earthquake.usgs.gov/earthquakes/world/seismicity_maps/.

Commemorating the 2011 Virginia earthquake

USGS, FEMA, CUSEC, and the National Park Service commemorated the one-year anniversary of the 2011 Virginia earthquake with a well-attended media event near the Washington Monument in the District of Columbia. At this event USGS reported on one-year research results, which were widely cited by Eastern U.S. news sources. Virginia earthquake research was also the focus of several special scientific sessions at professional meetings during 2012, which resulted in the publication of dozens of abstracts and several journal articles on the earthquake.

Developing new earthquake training courses

FEMA developed two earthquake training courses: *Earthquake Basics—Science, Risk, and Mitigation* (IS–325) and a train-the-trainer course, *Home and Business Earthquake Safety and Mitigation* (FEMA P–909). *Earthquake Basics* is a 30-minute independent study course available online via the Emergency Management Institute (EMI) that presents information on earthquake science, risk, and mitigation. The course targets homeowners, business owners, the private sector, the government workforce, first responders, nonprofit organizations, volunteers, and community-based organizations. The *Home and Business Earthquake Safety and Mitigation* course provides training on structural and nonstructural earthquake mitigation and is designed to create a cadre of trainers with the ability to provide basic knowledge on earthquakes and the steps that can be taken to mitigate seismic risk in homes and businesses. FEMA P–909 was rolled out in February 2012 at the *Earthquakes: Mean Business* events in Kansas City, MO.

FEMA NEHRP staff also contributed to the development of *Fundamentals of Building Science, Multi-Hazard Mitigation Design Concepts* (E–312). This classroom course, which is offered through FEMA's EMI, presents information on the impacts of earthquakes, high winds, flooding, and wildland/urban interface fires on the constructed environment, and explains key performance and construction issues related to those hazards. This popular course was offered in numerous venues and via webinars.

Conducting webinars on school safety

Many school buildings located across the United States are vulnerable to earthquake losses and damage, including deaths and injuries among students, teachers, and staff; damage to or the collapse of buildings; damage to and losses of furnishings, equipment, and other building contents; and the

disruption of educational programs and school operations. Through a series of FEMA-sponsored webinars based on *Incremental Seismic Rehabilitation of School Buildings (K–12): Providing Protection to People and Buildings* (FEMA 395), thousands of participants learned how to assess earthquake risks, develop plans to reduce and manage earthquake risks, secure nonstructural elements of school facilities, and apply "incremental seismic rehabilitation" to protect buildings and ensure occupant safety.

Learning from the past to protect the future: 2012 National Earthquake Conference

During April 10–13, 2012, FEMA staff gathered in Memphis with more than 600 partners in the earthquake and emergency management communities for the 2012 National Earthquake Conference. This important event, held every 4 years, is maintained largely through the commitment of NEHRP. The New Madrid earthquakes of 1811–1812 served as the backdrop for the conference venue and theme, "Learning from the Past to Protect the Future." EERI was the host of the conference and held its 64th Annual Meeting as part of the event. The conference was jointly organized and supported by FEMA, USGS, and the four FEMA-supported regional earthquake consortia. Before the official start of the conference, FEMA staff met with state earthquake program managers at their annual National Earthquake Program Managers meeting.

Objective 14: Develop the Nation's human resource base in earthquake safety fields

USGS support for external research partnerships

Government-university-industry collaboration advances targeted research and addresses specific needs of USGS by using the experience and knowledge of world experts. USGS provides competitive, peer-reviewed, external research support through grants and cooperative agreements that enlist the talents and expertise of the academic community, state governments, and the private sector. By involving the external community, USGS increases geographical and institutional impact, promotes earthquake awareness across the Nation, encourages the application of new hazards assessment techniques by state, local, tribal, and territorial governments and the private sector, and increases the level of technical knowledge within state, local, tribal, and territorial government agencies.

Investigations and activities supported through the external awards are closely coordinated with and complement internal USGS program goals. Many of the external projects are co-funded with other agencies and sources, leveraging USGS support. External program activities include the following: mapping seismic hazards in urban areas; developing credible earthquake planning scenarios that include loss estimates; defining the prehistoric record of large earthquakes; investigating the origins of earthquakes; improving methods for predicting earthquake effects; and developing a prototype earthquake early warning system (see previous discussion). USGS also has a cooperative agreement with SCEC, which is a 40-institution research consortium co-funded by USGS and NSF. In 2012 USGS awarded over 40 grants or cooperative agreements to over 20 institutions. A complete listing of those awards is available at http://earthquake.usgs.gov/research/external/research.php.

Providing research opportunities for undergraduates

NSF supports a number of Research Experiences for Undergraduates (REU) programs. The NEESreu program, led by Purdue University, is a 10-week summer research program for upper division undergraduate students interested in civil engineering, computer science/engineering, electrical engineering, and other fields related to seismic risk mitigation measures. Each NEESreu participant is paired with a faculty advisor, joins a NEES research team, and participates in research and enrichment activities, including attending the NEES Annual Meeting and Young Researchers' Symposium. In 2012, 29 NEESreu students joined faculty mentors at eight NEES research facilities. Students' papers detailing the results of their individual research projects are available at http://nees.org/neesreuprogramsummer2012. The Pacific Earthquake Engineering Research Center, based at UC Berkeley, coordinates another REU program that focuses on the theme of creating earthquake-resilient communities. In 2012, the center supported 12 summer REU students who conducted research projects in structural engineering, geotechnical engineering, urban planning, and public policy at UC Davis, UC Berkeley, and the University of Washington.

IRIS offers a third REU program that provides interns with opportunities to conduct research with state-of-the-art geophysical data and leading researchers at IRIS institutions. Students also develop an understanding of scientific inquiry, including designing and conducting scientific investigations, defending scientific arguments, and preparing publications. There were 15 interns in the IRIS program during 2012.

SCEC supports two student intern programs, with NSF support: Summer Undergraduate Research Experiences (SURE) and Undergraduate Studies in Earthquake Information Technology (UseIT). The SURE program, aimed at juniors and seniors in the earth sciences, pairs a student with a SCEC scientist at that researcher's institution or field site to work within that scientist's field of specialty. UseIT interns work on collaborative teams at SCEC to conduct computer science research that benefits earthquake science.

Teaching K–12 students about earthquakes

SCEC is active in the earth-science education community, participating in organizations such as the National Association of Geoscience Teachers, the Coalition for Earth System Education, and local and national science educator organizations. SCEC initiated a new Experiential Learning and Career Advancement program designed to promote undergraduate education within the larger context of science, technology, engineering, and mathematics (STEM) education and workforce development.

IRIS developed the Teachable Moment program to capture unplanned opportunities to bring knowledge, insight, and critical thinking to the classroom following newsworthy earthquakes. After significant earthquakes around the world, IRIS releases a Teachable Moment slide set in English and Spanish. Each slide set contains interpreted USGS regional tectonic maps and summaries, computer animations, seismograms, informative photos, and other event-specific information. These slide sets are generated within hours of the event, by seismologists and educators, and are a classroom-ready product that can be customized by teachers for their use.

Informal science education: Howard Ambassadors inspire future tsunami experts

In its second year of a collaboration with NEES, the Howard University Ambassadors Program engaged a diverse group of engineering students to work with underrepresented K–12 students in the Washington, D.C. area. NEEScomm (the NEES headquarters managed by Purdue University) provided the Howard University Department of Civil and Environmental Engineering with a 16-foot mini-wave flume developed by the NEES experimental facility at Oregon State University. The ambassadors program used the flume at the Discover Engineering Family Day event held in February 2012 at the National Building Museum in Washington, D.C. The flume was a popular part of the NEES exhibit booth at this annual event, which attracts more than 9,000 attendees from the area each year. Howard engineering students staffed the booth, introducing NEES, tsunamis, and earthquake engineering to the many interested children; operating the wave flume; and helping children design and build their own model structures, which were then tested in the flume against the tsunami waves generated by the ambassadors. As they left the booth, the children completed an assessment to share their new knowledge and excitement about the engineering profession. This activity not only stimulated interest in engineering among participating children, it also generated interest in undergraduate research related to tsunamis among participating ambassadors.

3.4 NEHRP Statutory Activity: Program Leadership

In performing statutory program management, coordination, and oversight functions during 2012, the NEHRP Interagency Coordinating Committee (ICC)[4] met once, the Advisory Committee on Earthquake Hazards Reduction (ACEHR)[5] met five times (including four teleconferences), and the working-level Program Coordination Working Group (PCWG) met 12 times. Program leadership activities are supported by the NEHRP Secretariat at NIST.

ICC responses to ACEHR recommendations

ACEHR delivered numerous recommendations and observations about NEHRP to the ICC in 2012. In November 2012, the Director of the NIST Engineering Laboratory, who is the Designated Federal Official for ACEHR and, thus, represents the ICC in interactions with ACEHR, provided feedback from the ICC on ACEHR's recommendations. The full text of the recommendations and corresponding feedback is available on the NEHRP website.[6]

NEHRP Secretariat operations

The NIST NEHRP Secretariat continued to provide support and leadership for program coordination that addresses earthquake safety and risk reduction issues nationwide. The office

[4] The ICC is composed of the Directors/Administrators of the four NEHRP agencies and the Directors of the Office of Management and Budget and the Office of Science and Technology Policy of the Executive Office of the President.

[5] ACEHR is composed of 16 nationally recognized, leading earthquake professionals who are not Federal employees and who are appointed to 3-year terms of service.

[6] See www.nehrp.gov/pdf/2012ACEHRReportFinal.pdf and www.nehrp.gov/pdf/ACEHRMeetingSummaryNov2012.pdf.

organized and conducted all ICC, ACEHR, and PCWG meetings and maintained the NEHRP website (www.nehrp.gov). This website provides information on NEHRP management efforts and products, and links to the four program agencies where further information on earthquake research results, current seismic activity, seismic hazard and risk, and earthquake mitigation practices can be found. NIST also initiated contracts with the NEHRP Consultants Joint Venture for two new program-wide planning activities, related to the future of NEHRP post-earthquake investigation activities and needed lifelines research.

3.5 NEHRP Statutory Activity: Develop, Operate, and Maintain NEHRP Facilities

PL 108–360 requires that NEHRP "develop, operate, and maintain" certain facilities essential to the NEHRP mission. These facilities are the Advanced National Seismic System (ANSS, maintained by USGS), the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES, maintained by NSF), and the Global Seismographic Network (GSN, maintained by both USGS and NSF). Below are reports on the activities and status of these facilities during 2012.

Advanced National Seismic System

The ongoing development of ANSS is focused on expanding and improving the performance and integration of national, regional, and urban seismic monitoring networks in the United States. The system consists of a national ANSS backbone network; the NEIC located in Golden, CO; 14 partner-operated regional networks located in areas of moderate-to-high seismic activity; and the National Engineering Strong Motion Project, which monitors earthquake shaking in structures.

The development of ANSS is about 30 percent complete. By the end of 2012, USGS and its partners had installed a cumulative total of 2,564 ANSS earthquake monitoring stations, including 1,634 channels of data recording in buildings and other structures. The network is now capable of detecting almost all felt earthquakes in the United States, except in remote areas of Alaska. The NEIC now typically reports on domestic earthquakes within minutes of their occurrence. The NEIC provides information on potentially damaging earthquakes to the National Command Center; the White House; the Departments of Defense, Homeland Security (including FEMA), Transportation, Energy, and the Interior; state offices for disaster services; numerous public and private infrastructure management centers (e.g., railroads and pipelines); the news media; and the public. Rapid earthquake notifications are delivered by e-mail and text message to over 355,000 subscribers, and a suite of earthquake information products (e.g., ShakeMaps, *Did You Feel It?* maps, technical data) is available on the USGS Earthquake Hazards Program website, which receives more than two million hits every day. USGS also provides near-real-time data to NOAA tsunami warning centers, supporting tsunami monitoring in the Pacific Rim and disaster-alerting in Alaska, Hawaii, Washington, California, and U.S. Territories in the Western Pacific.

As part of ANSS, USGS and cooperating universities operate 14 regional seismic networks in areas of moderate-to-high seismicity. Data from all U.S. regional seismic networks are used to monitor active faults and ground shaking with much greater detail and accuracy than is possible with the

national-scale network. Each region has appropriate local data processing capabilities, and regional data are contributed to a national ANSS catalog of earthquakes. ANSS regional networks serve as state or local distribution points for information about earthquakes to the public, local and state agencies, and other regional interests. The regional data centers also relay earthquake data in real time to the USGS NEIC, as well as to other regional networks. The centers provide information about regional earthquake hazards and risks and accepted mitigation practices, and those centers located at universities provide training and research facilities for students.

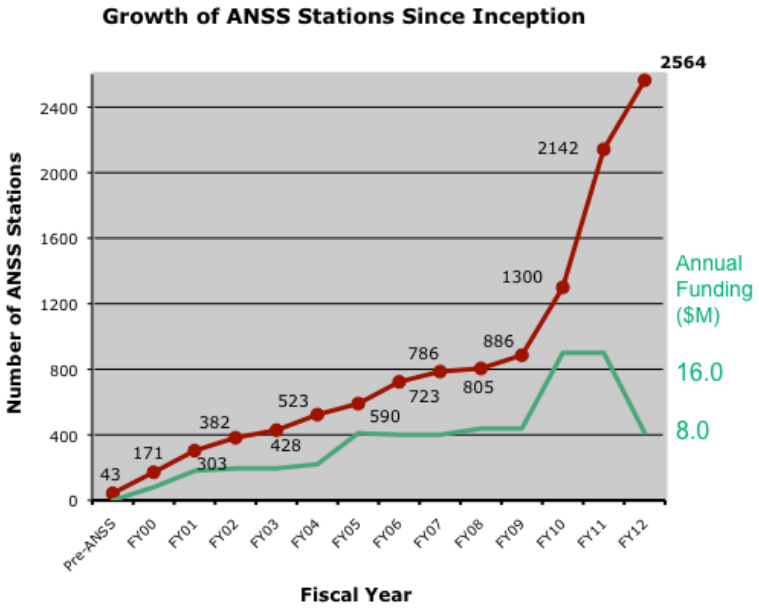


Figure 3–11. Growth of ANSS stations since the inception of the system. Also shown (in green) is the annual funding for ANSS development, which was supplemented during 2009–2011 by economic stimulus funding that allowed significant progress in ANSS implementation. Image courtesy of USGS.

Global Seismographic Network

The GSN provides high-quality seismic data to support earthquake alerts, tsunami warnings, hazard assessments, national security (through nuclear-test treaty monitoring), earthquake loss reduction, and research on earthquake sources and the structure and dynamics of the Earth. The GSN is a joint program supported by USGS and NSF and implemented by USGS, the Institute for Geophysics and Planetary Physics at the University of California, and IRIS, a university consortium sponsored by NSF. The network currently consists of 150 globally distributed stations. GSN instrumentation is capable of measuring and recording with high fidelity all seismic vibrations, from high-frequency, strong ground motions near an earthquake to the slowest global Earth oscillations excited by great earthquakes.

Because of its real-time data delivery, the GSN has become a critical element of continuous USGS hazard warning activities. Ninety-seven percent of GSN stations transmit real-time data continuously to the USGS NEIC, where these data are used, along with data from other networks, to rapidly determine locations, depths, magnitudes, and other parameters of earthquakes (and other seismic events) worldwide. The GSN also plays a major role in the operations of the NOAA tsunami warning centers in Hawaii and Alaska. GSN data are used by these centers to issue tsunami

alerts for all ocean basins of the world within a few minutes of the occurrence of tsunamigenic earthquakes. All GSN data are available to the public and scientists around the world via the IRIS Data Management Center. Data from the GSN are used extensively for basic and applied research on earthquakes, Earth structure, and other geophysical problems in studies conducted and supported by USGS, NSF, and other agencies such as the U.S. Department of Energy and the U.S. Air Force.

USGS tasks related to the GSN include maintaining and upgrading station facilities, monitoring and maintaining network telecommunications, troubleshooting problems, providing major repairs, conducting routine service visits to network stations, training station operators, providing direct financial aid in support of station operations at sites lacking a host organization, and ensuring data quality and completeness.

The GSN is continuing to upgrade its field acquisition systems across the network and to date has upgraded 105 of the 153 network stations to next-generation systems. Upgrades were substantially completed by the end of FY 2013, but upgrades to some stations in challenging global locations may occur later. The equipment for these upgrades was purchased with ARRA funds allocated by both USGS and NSF. These upgrades have significantly improved the reliability of GSN operations: data return has improved from 80 percent to 92 percent over the last 10 years. ARRA funds also supported the procurement of ancillary equipment (power systems, sensor interfaces, secondary sensors, etc.) that is being installed as part of the upgrade.

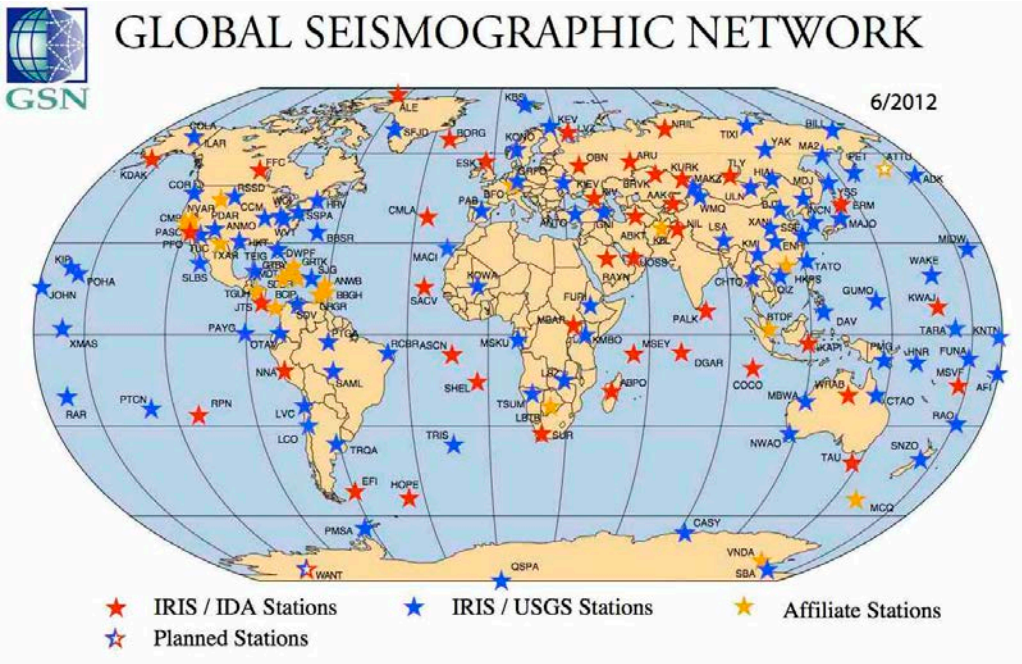


Figure 3–12. A map of the locations of the over 150 stations in the GSN as of June 2012.
© 2012 Image Courtesy of Incorporated Research Institutions for Seismology (IRIS).

In addition to supporting the acquisition system upgrades, NSF received $5.7 million in funding from the U.S. Department of Energy (DOE) to support the replacement of GSN primary sensors. These funds have been transferred to USGS, and will be utilized to procure sensors for use across the entire GSN. The IRIS instrumentation committee has been involved in defining specifications for this sensor procurement and the IRIS GSN program manager will sit as an observer on the selection committee for the USGS procurement. Preliminary procurements will be made for prototype systems in FY 2014, to allow for testing and evaluation. Based on these evaluations, a larger procurement may take place later in FY 2014. Final sensor costs still need to be determined, but NSF estimates that the allocated DOE funds will provide for replacement of approximately two-thirds of the primary sensors in the GSN.

George E. Brown, Jr. Network for Earthquake Engineering Simulation

NEES is a network of state-of-the-art laboratories and testing facilities, linked by a shared cyberinfrastructure, for studying earthquake and tsunami engineering. NEES began operations in 2004, supported by NSF, to enable research and innovation in earthquake and tsunami loss reduction, to create an educated workforce in hazard mitigation, and to conduct broader outreach and lifelong learning activities. In 2009, following a merit review re-competition process, NSF selected Purdue University to lead, manage, operate, and maintain NEES during fiscal years 2010–2014.

NEES consists of a managing headquarters (known as NEEScomm) located at Purdue University; 14 state-of-the-art earthquake engineering and tsunami experimental facilities located at and locally operated by universities across the United States; the NEEShub cyberinfrastructure framework; and the NEES Academy for education, outreach, and informal science education, which is powered by NEEShub. The 14 NEES experimental facilities are located at Cornell University; Lehigh University; Oregon State University; Rensselaer Polytechnic Institute; the University at Buffalo, State University of New York; UC Berkeley; UC Davis; UC Los Angeles; UC San Diego; UC Santa Barbara; the University of Illinois at Urbana-Champaign; the University of Minnesota, Twin Cities; the University of Nevada, Reno; and the University of Texas at Austin. These facilities include single (outdoor), dual, and triple shake tables; geotechnical centrifuges with in-flight biaxial shakers and robotic tools; a tsunami wave basin; laboratories for testing large-scale structures, soil-foundation-structure interaction systems, and lifeline systems; mobile geotechnical and structural field-testing equipment; and two permanently instrumented field sites in southern California.

NEEShub, which is based on HUBzero technology previously developed at Purdue University, serves as the central access point to robust, high-quality software tools and experimental databases for research. It helps researchers and practicing professionals to collaborate. Some of the resources that NEEShub provides include the following:

- Computing systems—NEEShub provides seamless access to high-performance computing venues, as well as abundant data storage space to support simulation, research, and other types of collaborative earthquake engineering data.

- Data—NEEShub stores publicly available earthquake engineering data, including experimental research results and concise, highly searchable repositories of earthquake engineering research data, vetted by professional communities and connected to original sources.
- Interoperable suite of software services and tools—NEEShub provides a unique and efficient environment for executing software tools, in which users are not required to download, install, or configure most software tools.

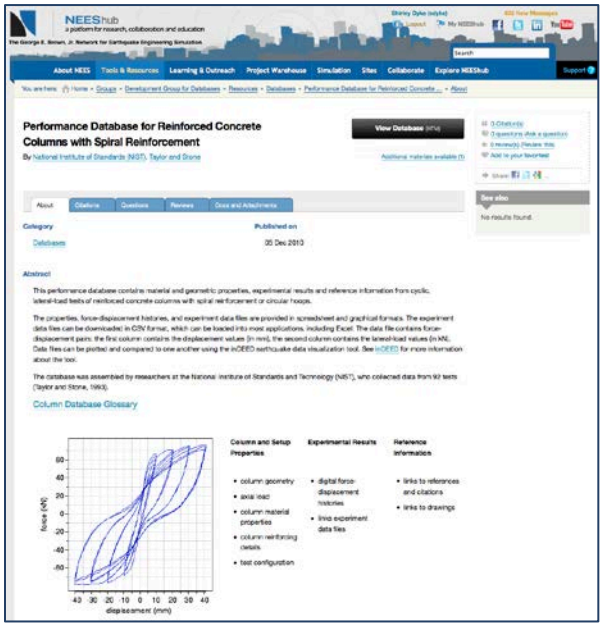


Figure 3–13. An example of content from the NEEShub cyberinfrastructure, specifically a database contribution on reinforced concrete columns with spiral reinforcement. © 2012 Image Courtesy of NEES.

The NEES Academy provides a community resource for educational materials, online learning, and outreach for students of all ages. It supports outreach to the profession, providing a mechanism to bridge from theories to practice and identify the needs of practice to researchers. Faculty and staff at the NEES facilities support ongoing local outreach efforts, such as K–12 camps, museum exhibits, and informal science education. NEEScomm organizes the NEES annual meetings that bring together both NSF-supported researchers using the NEES infrastructure and the distributed NEES operations team to share research findings, information about NEES experimental and cyberinfrastructure resources, and effective methods for education and outreach in earthquake engineering. This year's meeting, Quake Summit 2012, was held July 9-12, 2012, in Boston, MA.

NEES will complete its 10 years of NSF funding at the end of FY 2014. Through a program solicitation issued in FY 2013, NSF intends to recompete, as an integrated research infrastructure, the managing NEES headquarters, cyberinfrastructure, reduced number of experimental facilities, and education and outreach activities, referred to as "NEES2," for FY 2015 - FY 2019.

Section 4

State and Territory Activities to Promote Implementation of Research Results and Hazard Mitigation Efforts

The NEHRP Reauthorization Act of 2004 (PL 108–360) directed FEMA to operate a program of direct assistance to states to accomplish various eligible earthquake safety and mitigation activities. FEMA created the NEHRP Earthquake State Assistance Program to increase and enhance the effective implementation of earthquake risk reduction at the local level. Under this program, FEMA awards cooperative agreements to states and territories with moderate-to-high seismic risks to fund eligible risk-reduction activities. This funding supports programs for implementing earthquake safety, mitigation, and resilience activities at the local level. Eligible risk-reduction activities include developing seismic mitigation plans; preparing inventories and conducting seismic safety inspections of critical structures and lifelines; updating building codes, zoning codes, and ordinances to enhance seismic safety; increasing earthquake awareness and education; and developing local consortia for earthquake risk reduction.

Highlights of successful state, territorial, and local government efforts in 2012 are presented below. FEMA awarded 22 cooperative agreements totaling approximately $1,114,533 to selected states and territories with high seismic risks. Each agreement funded two or more eligible activities that supported the establishment of local earthquake risk reduction programs and implementation of earthquake safety, mitigation, and resilience activities.

Alabama

Alabama undertook a number of important activities, including providing slide presentations at outreach events across the State; planning for ShakeOut activities; updating an 8th grade earthquake science curriculum; updating the State Emergency Operations Plan; conducting training on FEMA 154/ATC–20; updating relevant State web pages; and working in collaboration with other States on CAPSTONE–14, which is a 3-year multistate planning and preparedness effort that will culminate in a multistate earthquake preparedness exercise in June 2014. The University of Alabama-Tuscaloosa is developing a 17- by 17-foot earthquake simulator. Alabama is also planning to establish a State Seismic Safety Council.

Alaska

Alaska supported an active earthquake mitigation program in close partnership with the Alaska Seismic Hazard Safety Commission (ASHSC) and other groups. The ASHSC Scenario Committee provided FEMA Region X planners and the Alaska Shield 2014 planning team with three viable earthquake scenarios for Alaska. The Alaska Earthquake Information Center developed ShakeMaps, and the University of Alaska-Geophysical Institute Tsunami Modeling Group and the Alaska and West Coast Tsunami Warning Center provided tsunami wave height data to support the planning scenarios. Alaska Shield 2014 is an important exercise scheduled to coincide with the 50th

anniversary of the 1964 Good Friday earthquake. It will involve Federal, State, tribal, and local partners, testing their response to a major earthquake and resulting tsunamis that generate rescue, sheltering, and casualty-care needs. The Alaska Division of Homeland Security and Emergency Management also partnered with the ASHSC to sponsor a training course on post-earthquake safety inspections of buildings, using FEMA ATC–20 materials. Forty-three engineers, architects, and facility and construction managers from multiple Alaska jurisdictions and the private sector completed the course.

In regard to outreach, State staff, in coordination with FEMA Region X, launched the Great Alaska ShakeOut website, registering more than 50,000 participants for the 2012 event. Staff also took the "Quake Cabin," an earthquake motion simulator used to teach nonstructural seismic hazard mitigation and preparedness, to more than a dozen health, safety, and preparedness fairs. A statewide planning effort was begun to commemorate the 50th anniversary of the Good Friday earthquake, led by the Anchorage Museum. To improve earthquake resilience, Chugach Electric Corporation completed the seismic stabilization of electrical generation transformers in the major South-central Alaska power generation facility. Other seismic safety advancements included an assessment of the seismic structural safety of two K–12 schools in the Anchorage School District, which provided a benchmark for 117 Anchorage district schools, and the completion of seismic retrofit projects for local public schools and fire stations in the Kodiak Island Borough and Anchorage.

American Samoa

American Samoa organized a successful ShakeOut exercise with the participation of six schools and one government department. Since then, American Samoa has received requests from schools and government departments that want to participate in the next annual ShakeOut. Posters and drill manuals were distributed, and earthquake preparedness presentations were conducted during pre-ShakeOut events. Students, faculty, parents, and the private and public sectors have taken more of an interest in learning how to prepare for seismic hazards.

The delivery of visual reminders, via signs, posters, and advertisements on earthquake mitigation and education, has been a prominent tactic in public earthquake messaging on the island. American Samoa posted "Drop, Cover, and Hold On" signs across the island, and there have been many local newspaper advertisements on earthquake safety tips and terminology.

Arizona

The State joined forces with the ShakeOut movement in the first Great Arizona ShakeOut, with more than 65,000 people participating. The Arizona Geological Survey and the Arizona Department of Emergency Management worked together to organize multiple ShakeOut events and presentations. Targeted participants included county and municipal emergency managers, communities, the Red Cross, and school districts in areas that have known earthquake risks.

The State also pursued additional outreach activities, including developing, printing, and distributing earthquake preparedness brochures for Yuma, Yavapai, and Coconino Counties; publishing videos regarding the nature of seismicity and earthquake hazards and risks in Arizona; developing the *Arizona is Earthquake Country* publication; publishing articles on the Groundswell Earthquake Outreach Blog; and maintaining Twitter and Facebook accounts with seismicity and earthquake mitigation information.

Arkansas

Arkansas continues to promote earthquake loss reduction through mitigation. The State earthquake program manager spoke at the Arkansas State University Science, Technology, Engineering, and Math Teacher Development Seminar on the history of earthquakes, local seismic threats, and the importance of preparedness and mitigation measures. Brochures and posters were provided to teachers for their classrooms. Arkansas is promoting public education and outreach through teachers in at-risk counties and is enhancing public awareness and encouraging individual preparedness. In addition, State staff are working with the University of Arkansas for Medical Sciences to implement nonstructural mitigation in two buildings on campus and are conducting a site assessment of Walnut Ridge Airport for medical evacuation/staging in case of an earthquake or other natural disaster. Arkansas also hosted FEMA E–74 training (*Reducing the Risks of Nonstructural Earthquake Damage*) for building owners, business proprietors, risk managers, and State and local emergency managers, among others, during earthquake preparedness week.

California

Highlights of California's seismic risk reduction efforts include continued development of the California Integrated Seismic Network monitoring system; participation with USGS, UC Berkeley, and Caltech in earthquake early warning research and the development of operational earthquake forecasting; support for the California Earthquake Country Alliance (ECA) "whole community" collaboration among earthquake education stakeholders; and support for ECA's flagship product, the Great California ShakeOut. The 2012 ShakeOut included a record number of participating Californians and featured commuter preparedness as a sub-theme, with 50,000 NEHRP-funded public transit "tip cards" distributed by transit company partners. ECA's statewide committees also produced materials providing ShakeOut tips for businesses and self-protection guidance for those with limited mobility.

California continues to assess the seismic vulnerabilities of State-owned buildings through its California Vital Infrastructure Vulnerability Assessment (Cal VIVA) mitigation project. California also continued to work closely with several partners on the State's priority projects, including with EERI on continued support of Cal VIVA and the Concrete Coalition's continued assessment of and mitigation guidance for non-ductile buildings, and with SCEC on continued support of ECA and ShakeOut.

Colorado

The Colorado Earthquake Hazard Mitigation Council continued to meet bimonthly at the Colorado School of Mines. The council also collaborated with FEMA Region VIII, the Structural Engineers Association of Colorado, the Colorado Geological Survey, and the Colorado Office of Emergency Management to provide training on ATC–20, FEMA 154, and ROVER. More than 50 participants attended this free training at the University of Colorado-Denver.

Guam

In collaboration with Guam Homeland Security and the Guam Earthquake Advisory Committee, Guam improved its emergency response force; increased earthquake awareness, outreach, and education; conducted training and exercises; established and participated in multi-jurisdiction groups; produced and distributed seismic mitigation materials; and updated local seismic codes to enhance safety for residents and visitors. Guam also orchestrated a robust ShakeOut media campaign that involved participant recruitment; product design, development, printing, and dissemination; and public education and localized outreach efforts targeting schools. ShakeOut materials used included brochures, cards, teaching aids, and posters. There were more than 65,000 participants in the 2012 Guam ShakeOut.

Hawaii

NEHRP funds supported two main efforts in Hawaii: the activities of the Hawaii State Earthquake Advisory Committee (HSEAC) and the earthquake public outreach program. These efforts entailed collaboration with partners from State, county, and Federal agencies, including experts from the Hawaii State Civil Defense agency, National Weather Service, and Pacific Tsunami Warning Center.

The HSEAC is composed of seismic experts who are integral to the success of State earthquake mitigation efforts. Activities under the purview of this committee include reviewing and updating the seismic portions of the State and county mitigation plans; conducting seismic safety inspections and inventories of critical structures and lifelines; reviewing building codes, zoning codes, and ordinances for the purpose of enhancing seismic safety; increasing earthquake awareness and education; developing seismic project and program proposals; and making recommendations through the State Hazard Mitigation Forum on projects and project priorities.

The earthquake public outreach program educates the public about seismic risks by developing and disseminating outreach tools, publications, and presentations. One project provides hazard awareness training to Hawaii's schoolteachers through enhancements to their natural sciences curriculum. The earthquake module includes a public education element that covers earthquakes and associated hazards, how earthquakes cause damage, aftermath risks, and the actions individuals can take to mitigate and minimize damage to their homes and injuries to their families. This is followed by a structured training program for teachers that provides them with more in-depth scientific and technical information, as well as guidance and assistance in developing lesson plans that address the science of earthquakes, their social and economic impacts, and strategies for reducing their damage to the community.

Idaho

The Idaho ShakeOut was conducted. Other activities included revising the State mitigation plan, conducting a school-seismic-needs-assessment pilot project in cooperation with the State of Washington, and revising the earthquake preparedness guide for Idaho. Initial planning was begun for an earthquake scenario in eastern Idaho that will include the failure of Palisades Dam. There have been many cases of landslides in Idaho and, as a result, canal and levee safety has become an important issue. Unmapped faults continue to be a concern to the State. Idaho does not have monitoring equipment for earthquakes (equipment in Wyoming is used) and is attempting to identify funding for its own seismic monitoring equipment.

Illinois

February is Earthquake Preparedness Month in Illinois. Preparedness and awareness activities were conducted during that month and throughout the year, including issuing news releases and updating and distributing publications. In the months before the ShakeOut event, Illinois encouraged participation through mailings, personal contacts, speaking engagements, websites, social media, print and radio advertisements, and media events. ShakeOut registrations in Illinois numbered more than 490,000.

Two ATC–20 courses were held in southern Illinois, with a total of 118 attendees. Under contract with the Illinois Emergency Management Agency (IEMA), Southern Illinois University conducted 26 earthquake awareness presentations for schoolchildren and civic organizations. The mitigation course *Reducing the Risks of Nonstructural Earthquake Damage* (FEMA E–74) was offered during the IEMA Annual Conference. In addition, staff attended the CAPSTONE–14 Private-Sector Workshop in Chicago and the National Earthquake Program Managers Meeting and National Earthquake Conference in Memphis. Illinois continued to develop a framework for training, equipping, and deploying earthquake inspectors.

Kentucky

Kentucky conducted a new video contest for elementary and high-school students. The winning high-school video shows simple steps that home owners can take to protect their families and homes from earthquakes. Because of the success of the video contest, there are now plans to set up a writing contest for middle-school students. Kentucky also is working on the CAPSTONE–14 multi-state planning and preparedness exercise. CAPSTONE-14 is a three-year planning and preparedness activity of the Central U.S. Earthquake Consortium (CUSEC) that will culminate in a major multi-state earthquake exercise in June 2014.

Maine

Maine developed earthquake safety curricula and brochures for K–12 schools. These products were sent to more than 500 schools. Maine also developed a FEMA 154 (*Rapid Visual Screening of Buildings for Potential Seismic Hazards*) inventory of critical facilities and public buildings in eight counties. The resulting data were entered into the State Geographic Information System (GIS) and HAZUS for an analysis of earthquake risk conducted by college interns who had been trained in FEMA 154 and

HAZUS. The State earthquake program manager attended the National Earthquake Conference in Memphis.

Missouri

In February 2012, Missouri held the *Earthquakes: Mean Business* seminar for businesses at St. Louis University. The State and FEMA sponsored and exhibited at the event. Also in February, the New Madrid Earthquake Meeting was held at Missouri University Student Center in Columbia.

Missouri completed nonstructural seismic mitigation projects on Sikeston School and the Bloomfield School, and a flyer was produced to publicize this work. Seismic mitigation work was initiated on Kennett Middle School and Notre Dame High School in Cape Girardeau. This work involves extensive nonstructural mitigation.

NEHRP State assistance funds also were used to support the Missouri Structural Assessment and Visual Evaluation Coalition; training for pre-earthquake and post-earthquake building inspectors; purchases of supplies; and building-inspection exercises at disaster sites. Outreach activities in Missouri included earthquake-related displays in museums and the Great Central U.S. ShakeOut, which involved activities at five schools, news releases, and personal appearances and presentations as requested throughout the State. Missouri also produced and distributed a new poster on earthquakes; supported the disaster safety outreach program "Map Your Neighborhood" with public training and presentations in six communities; and held another earthquake poster contest for third, fourth, and fifth graders.

Montana

For more than 10 years, FEMA assistance has supported the ongoing development of Montana's State and local hazard mitigation plans. The plans have included earthquake and landslide risk assessments, credible earthquake scenarios for local and State emergency managers, and statewide earthquake hazard maps that provide greater detail than national hazard maps. FEMA support also has helped Montana's Dam Safety Program address seismic risk. The seismic monitoring efforts of the Montana Bureau of Mines and Geology and the bureau's earthquake catalog provide critical data for creating and maintaining the USGS national seismic hazard maps that support the development, adoption, and implementation of seismic-resistant building codes in Montana. These ongoing efforts will improve the transparency of the State's inputs to the USGS hazard maps, which should support seismic building code adoption and enforcement in Montana. In addition, the data on seismicity in Montana helps delineate seismogenic sources that are incorporated into the USGS hazard maps, further adding value to the data that support the building code.

Montana is working to make its 1982–2012 earthquake catalog publicly available to provide visual, easy, and versatile access to Montana's extensive historical earthquake record. Improved access to these data—including current seismicity data—will enhance Montana's seismic hazard education and outreach efforts, and support continued State and local seismic hazard mitigation planning.

Nevada

Highlights of Nevada's earthquake risk reduction accomplishments include significantly increased participation in the Great Nevada ShakeOut, which surpassed 516,000 participants from all counties and public school districts. The increased participation reflects greater involvement by schools and local governments in Clark County, Henderson, and Las Vegas. Activities included a press conference attended by the mayor of Las Vegas 3 days before the ShakeOut, and a similar event held soon after in Washoe County. Future goals for ShakeOut include the participation of more hospitals and casinos.

Nevada enhanced the automation surrounding its HAZUS software to improve the reliability of the damage estimates that can be produced immediately after a damaging earthquake in the greater Reno area and elsewhere. Ideally, all automated earthquake activities, ranging from earthquake monitoring to ShakeMap production to HAZUS runs, should be housed within the Nevada Seismological Laboratory (NSL) data center, which has backup power and air conditioning. Automation of ShakeMap products is under way through access to several servers at the Nevada Bureau of Mines and Geology and the NSL, which should expedite real-time response.

New Mexico

New Mexico supported a seismic vulnerability assessment of eight counties in the State. The State also adapted the FEMA Tremor Troop and Seismic Sleuth educational materials so that they will be more suitable for New Mexico.

Oklahoma

In response to two back-to-back earthquakes (M3.4 and M4.1), preliminary damage assessments were conducted on more than 200 homes in two counties. Six homes were destroyed, 21 homes had major damage, and 37 homes had minor damage. The counties did not qualify for assistance from FEMA. A declaration from the U.S. Small Business Administration (SBA) was requested to enable SBA loans. Of the 97 SBA loans applied for, 57 were approved, totaling more than $2 million. Oklahoma also participated in the Great Central U.S. ShakeOut. There were about 65,000 participants from Oklahoma, a large increase over the previous year, when 10,000 participated.

Oregon

The Oregon Earthquake Hazard Reduction Program completed several projects in partnership with the Oregon Seismic Safety Policy Advisory Commission (OSSPAC), the Oregon Department of Geology and Mineral Industries (DOGAMI), and FEMA.

Personnel from the Oregon Office of Emergency Management (OEM) spent 3 weeks in March 2012 visiting all of the coastal counties in a Tsunami Road Show. More than two dozen events were held to promote earthquake and tsunami preparedness. Other partners joined in these events, including the American Red Cross, DOGAMI, Oregon State University, and many local first responders and emergency management agencies. The second annual Great Oregon ShakeOut was

also held this year, and for the first time it was promoted statewide. More than 160,000 people registered to participate in the earthquake drill.

OEM updated the *Seismic Hazards Media Guidebook* and made it available in print and electronically. The publication covers earthquakes, tsunamis, and volcanoes, and helps the media to better understand these hazards.

The Oregon legislature recognized the scale of the Cascadia Subduction Zone threat when it passed House Resolution 3 in 2011, noting the likely impact of a Cascadia earthquake and the need for a plan to move Oregon toward resilience. OSSPAC was charged with developing a resilience plan. The resulting report summarizes the science of Cascadia Subduction Zone earthquakes, estimates their impacts, and provides a detailed analysis of the current vulnerability of buildings, the business community, and transportation, energy, communication, and water/wastewater systems. The report defines performance targets that need to be met in order for each sector to achieve resilience, and provides recommendations on how to meet these targets over the next 50 years. More than 150 volunteers donated their time and expertise to this project. The report was presented to the legislature in February 2013, and made available on the OEM website at http://www.oregon.gov/OMD/OEM/osspac/docs/Oregon_Resilience_Plan_draft_Executive_Summary.pdf.

The South Beach Tsunami Interpretive and Evacuation Trail is being developed under a cooperative effort involving the City of Newport, the Hatfield Marine Science Center, Lincoln County, DOGAMI, and OEM. This project is creating and installing a series of tsunami interpretive signs along a route in the South Beach area of Newport in Lincoln County. The number and locations of the signs were determined by the South Beach Tsunami Trail workgroup, and a total of 10 signs were installed this year. In future years, the interpretive trail will be expanded into the local port facility and will connect to the Japanese Tsunami Memorial at the Hatfield Marine Science Center.

Puerto Rico

FEMA NETAP training tailored to the region was held in Puerto Rico, with about 175 attendees, including more than 100 engineers. The Puerto Rico Seismic Network took a lead role in planning and coordinating ShakeOut events. FEMA helped with the translation of documents for the Puerto Rico ShakeOut website and met with the Puerto Rico Emergency Management Agency to discuss a press release and press conference for ShakeOut. FEMA staff also participated in a vertical evacuation workshop hosted by the Puerto Rico Seismic Network, which used *Vertical Evacuation from Tsunamis: A Guide for Community Officials* (FEMA P–646a) as a resource document.

South Carolina

South Carolina sponsored an earthquake display at the South Carolina State Museum; conducted annual HAZUS training for county officials; and updated State seismic maps to show the history of earthquakes by region. As a result of the updates, the maps have been transitioned into a guide format. Upcoming projects include a workshop with the University of South Carolina for K–12

educators on how to increase students' interest in and enthusiasm for science, and the planned reactivation of the South Carolina Seismic Safety Commission.

Tennessee

Tennessee partnered with CUSEC, the Center for Earthquake Research and Information at the University of Memphis, and USGS to produce a 22-minute documentary on the historical significance of the New Madrid Fault Zone and the likely effects of an earthquake in West Tennessee. This documentary explains how the New Madrid Fault differs from other faults in the United States. It also discusses preparedness and mitigation. The documentary has been shown in all major television markets in Tennessee and has been approved by National Public Television for national distribution. It has been shown more than 300 times to nearly 16 million people and used in 120 public meetings held at schools, universities, churches, and public-service organizations throughout Tennessee.

Utah

The Utah Earthquake Program is a collaborative effort of the Utah Geological Survey, the Utah Seismic Safety Commission (USSC), the University of Utah Seismograph Stations, the Structural Engineers Association of Utah (SEAU), and the Utah Division of Emergency Management. Recent projects have included inventorying school buildings, updating an unreinforced masonry residential rehabilitation guide, developing earthquake educational materials, inventorying hospitals along the Wasatch Front (building type, year built, number of beds, and retrofit information), updating and printing the booklet *Putting Down Roots in Earthquake Country: Your Handbook for Earthquakes in Utah,* designing and installing an Earthquake Center in the new State Emergency Operations Center, and holding a joint meeting of the USSC and the Nevada Earthquake Safety Council.

A joint USSC–SEAU committee completed its sample seismic hazard inventory of Utah schools, using FEMA's ROVER software to gather the field data. After reviewing the results of the sample inventory, the committee prepared a report for the State legislature—*Utah Students at Risk: The Earthquake Hazards of School Buildings*—in support of House Bills 367 (*Utah Schools Seismic Hazard Inventory*) and 423 (*Public School Seismic Safety Committee*).

More than 940,000 people participated in the Great Utah ShakeOut. Accompanying events included a 3-day, full-scale, functional local-State-Federal earthquake exercise. More than one-third of Utah residents participated in the 2012 ShakeOut, the highest participation ever achieved in a statewide earthquake drill. Outreach activities included extensive media coverage, production and dissemination of the new video *Utah: Preparedness Now*, and publication of a suite of scenario earthquakes online to help communicate earthquake risk across Utah (www.shakeout.org/utah/).

Vermont

Vermont continued seismic hazard mapping and mitigation outreach efforts for Burlington and Colchester. The mapping is at a scale that is useful for State and local facility owners, emergency managers, and hazard mitigation planners, among others. The maps have been presented to the

Northeast States Emergency Consortium (NESEC) state geologists as a regional model and also to critical facility owners for mitigation and preparedness planning. Vermont has combined the mapping outreach meetings with FEMA E–74 training (*Reducing the Risks of Nonstructural Earthquake Damage*).

Virgin Islands

Television public service announcements about earthquakes and tsunamis were created to inform large and diverse portions of the population about earthquake issues. The announcements received positive audience feedback. Earthquake and tsunami presentations were conducted at public and private schools, non-governmental organizations, churches, community centers, and home owner associations. FEMA NETAP training for about 30 participants was also held in the Virgin Islands.

Washington

Washington continued to make seismic risk reduction a high emergency management priority. The Washington State Seismic Safety Committee (SSC) initiated a multiyear planning effort by engaging more than 70 stakeholders to assist the SSC in assessing current vulnerabilities to seismic hazards, examining critical interdependencies between and across infrastructure sectors (utilities, housing and economic development, critical services, and transportation), establishing performance metrics for the post-earthquake restoration of services and infrastructure, and providing a blueprint for long-term risk reduction policy implementation to improve Washington's resilience for earthquakes and other hazards. The final report will provide guidance on how to facilitate long-term implementation of seismic risk reduction policies, with the goal of making Washington resilient within 50 years. Preliminary lessons from resilience planning in Washington have been shared through the Cascadia Region Earthquake Workgroup (CREW) and have served as a model for Oregon, which recently initiated a similar effort.

Several Washington agencies and the SSC developed an approach for systematically evaluating seismic risk for all public school buildings and critical facilities in Washington. This approach was piloted in two school districts. Enhanced screening and preliminary seismic retrofitting options were developed for four critically deficient school buildings identified in an earlier project. The results of this study are being used by the school districts to justify applications for FEMA grant funds to seismically retrofit deficient structures.

Washington joined the ShakeOut movement and had more than 710,000 participants from schools, private industry, and other organizations join in this inaugural drill. Leveraging NEHRP resources, Washington also used funding provided under the Tsunami Warning and Education Act to incorporate a coastal tsunami siren test and evacuation drill into the ShakeOut campaign. This enabled all Washington residents to become familiar with these hazards and increase their personal preparedness so that they can take the appropriate life-safety actions when necessary.

Figure 4–1. Washington State joined the international ShakeOut movement and had more than 710,000 participants from schools (including these children from the Sumner Middle School), private industry, and elsewhere join in the drill.
© 2012 Image Courtesy of Barbara Thurman.

Wyoming

The Wyoming Office of Homeland Security is building capacity through ATC–20 (*Post-Earthquake Safety Evaluation of Buildings*), FEMA 154 (*Rapid Visual Screening of Buildings for Potential Seismic Hazards*), and ROVER training and the development of a database of critical infrastructure and lifelines with elevated seismic risk. The database will also provide direction for effective seismic mitigation activity. A ROVER-based inventory of critical building assets was initiated and completed by students in 2013.

Section 5
NEHRP Response to Major Earthquakes in 2012

Mineral, Virginia

An earthquake felt throughout the Eastern United States occurred on August 23, 2011. The epicenter was in central Virginia's Louisa County near the small town of Mineral, about 50 kilometers (km) east of Charlottesville, 60 km northwest of Richmond, and 130 km southwest of Washington, D.C. The M5.8 earthquake caused about $200 million of damage in Virginia and Washington, and is among the largest earthquakes on the eastern seaboard during the approximately 400-year historical record. Several aftershocks as strong as M4.5 occurred after the main tremor.

While this earthquake occurred before the beginning of FY 2012, many response and research activities of the NEHRP agencies related to this event extended into 2012. This earthquake provided an opportunity for scientists to learn more about the causes of seismicity in the Eastern United States. Eastern North America has a long history of infrequent, but sometimes large and damaging, earthquakes. Unlike seismic activity that is concentrated along plate boundaries, earthquakes in the passive margin of eastern North America are not clearly identified with active faults, but the underlying, causal processes of strain concentration and release is well understood.

USGS research on the cause of the earthquake

In response to the Mineral earthquake, USGS and partnering organizations acquired or sponsored the collection of several geophysical, seismological, and geologic data sets to facilitate characterization of the earthquake region. Research included mapping of the causative fault and associated buried geologic features; assessment of estimates of regional ground motion variability; and measurements describing local amplification of seismic energy. The research goal is to understand how often earthquakes like this have happened in the region and whether a similar or larger earthquake is likely to happen in the future.

The deployment of 46 portable seismic stations by several organizations within days following the earthquake, along with easy access to the resulting aftershock records, greatly aided earthquake fault characterization and studies of regional ground motion variability. Aftershock data recorded by these stations allowed delineation of the probable causative fault.

In March 2012, USGS collected a high-resolution light detection and ranging (LiDAR) survey over an approximately 20 km by 35 km area covering the epicenters of the earthquake and most aftershocks. In July 2012, USGS sponsored the collection of high-resolution, airborne magnetic, gravity, and radiometric surveys over a similar but slightly smaller area. The gravity and magnetic data inform researchers about subsurface features, while LiDAR and radiometric data, respectively, delineate subtle features at the land surface and will help to characterize long-term earthquake

activity beyond the 400-year historical record. Detailed analyses to interpret these data are under way.

GEER geotechnical investigations

Geotechnical Extreme Events Reconnaissance (GEER), with support from NSF, mobilized a team to investigate geotechnical effects of the earthquake. Team findings were reported in October 2011. Few instances were found of ground failure produced by this earthquake, but the team found minor liquefaction and slumping along some streams, minor separation of approach abutments from bridge bents, rockfalls, and slope movements in marginally stable slopes, with most observations made in the epicentral region. Although there were few sites of ground failure, there were observations important to the geotechnical engineering community. Of particular significance was a clear correlation between geotechnical conditions and damage from this event, especially in the National Capital Region. It was clear that soil amplification in soft sediments overlying hard rock influenced damage and shaking intensity patterns, as did the underlying geologic structure associated with the Appalachian Mountains and the strike of regional geologic faulting.

NSF RAPID grants

NSF funded several RAPID grants to research the region's earthquake mechanisms. One grant funded researchers to test a novel type of high-density aftershock deployment using EarthScope Flexible Array instruments. After the earthquake, the Advanced Information and Data Acquisition system deployed 201 stations in three phases. The survey was designed to record wavefields at sufficiently dense spacing to minimize spatial aliasing and lower the event detection threshold. This enabled aftershock locations to be determined with high precision and the imaging of geologic structure with resolution on par with typical controlled-source crustal surveys. The resulting high-resolution subsurface images and aftershock characterization not only define key geologic relationships at depth for this important intraplate hypocentral region, but also provide a template for future high-density aftershock deployments.

Another RAPID grant supported researchers to instrument the region surrounding the epicentral zone with seismometers and GPS receivers to record aftershocks and subtle ground movements for a year. These measurements allow geoscientists to visualize the fault that ruptured in 2011 and better understand the state of stress in the crust that led to the earthquake. This employs seven seismometers available from the IRIS instrument pool and two new GPS receivers that will be constructed following Plate Boundary Observatory specifications.

NSF also made two collaborative RAPID awards to Lehigh University and Virginia Tech to study damage to structures in Washington, D.C., where there was significant damage to a number of structures that was unexpected and more severe than damage to structures located closer to the epicenter. Damage occurred at the Washington Monument and the Smithsonian Institution's Museum Support Center. This was a unique opportunity to analyze the behavior of east coast structures, which generally are not designed to resist earthquakes, including interactions between key engineering factors and specific geologic and geotechnical conditions underlying the Washington

area. The work promotes advances in building codes and design procedures specific to the Eastern United States, and increases our understanding of the possible impacts of future earthquakes in the Washington, D.C., area.

Figure 5–1. Engineers conducting an exterior assessment of the Washington Monument, which was damaged in the Mineral, VA, earthquake. Image courtesy of the National Park Service.

FEMA planning, outreach, and education activities

Even though earthquake damage was documented in the District of Columbia, Delaware, Maryland, Pennsylvania, Virginia, and West Virginia, these areas did not receive state earthquake assistance funds from FEMA in FY 2012 based on research showing them as having low seismic risk. However, a number of planning, outreach, and educational activities were undertaken following the Mineral earthquake. In January 2012, FEMA staff met with local, state, and Joint Field Office leaders to discuss earthquake issues. These discussions focused on (a) the vulnerability of homes, government buildings, hospitals, educational institutions, and critical structures to earthquakes, (b) a comparison of the Mineral earthquake to the recent earthquakes in Haiti, Japan, and Chile, (c) the opportunities to mitigate damage and reduce loss of life through the adoption of enhanced building codes, as evidenced by the Chile experience, (d) the history of seismic activity on the East Coast documented in seismic hazard maps, and (e) the potential for damage and losses from future earthquakes. FEMA also promoted the ROVER software tool as a best practice for preparing for and mitigating against earthquake risk.

Van, Turkey

With support from the U.S. Agency for International Development, a USGS Earthquake Disaster Assistance Team that included earthquake scientists and engineers responded to a major earthquake in eastern Turkey. The October 2011, M7.1 main shock near Van, Turkey, was followed by several weeks of earthquakes greater than M5, which together caused over 600 fatalities, 2,500 injuries, and either the collapse of or severe damage to 1,200 buildings. The USGS team collaborated with

colleagues from the Turkish Government's Disaster Response and Management Agency and several Turkish universities to investigate geologic aspects of the earthquake and the effects of shaking on the built environment.

The investigators found that fault rupturing during the earthquake's main shock did not break the ground surface; instead, it produced broad folding and about a meter of uplift best seen through comparison of pre- and post-earthquake satellite imagery. Faults like this are typically poorly expressed at the ground surface and, thus, the contribution of such faults to regional hazards is often underestimated or unrecognized. The long series of moderate aftershocks, coupled with the seismic vulnerability of buildings—primarily mid-rise, framed reinforced concrete structures with brick infill walls—posed extra challenges for the emergency response to this earthquake. In the city of Van, five buildings collapsed during the main shock, but a M5.6 aftershock 2 weeks later caused 30 additional buildings to collapse. The team recommended that shear walls be incorporated in future buildings. Since the earthquake occurred, the Turkish Government announced the completion of more than 15,000 housing units built with shear walls that were to be allocated to families that lost their homes in the earthquake. For more information on this work, see www.nehrp.gov/pdf/SeismicWavesAug12.pdf.

Section 6
Related Activities Supporting NEHRP Goals

PL 108–360, the Earthquake Hazards Reduction Program Reauthorization Act of 2004, requires that NEHRP's annual report to Congress include a description of activities being carried out by the NEHRP agencies that contribute to program goals but are not officially included in the program. Highlights of these programs and activities are described below.

6.1 Interagency Committee on Seismic Safety in Construction

The Interagency Committee on Seismic Safety in Construction (ICSSC) released *Standards of Seismic Safety for Existing Federally Owned and Leased Buildings, ICSSC Recommended Practice 8* (NIST GCR 11–917–12). The Building Seismic Safety Council prepared the new standards document for NIST, which acted on behalf of the ICSSC. The new standards provide guidance for use by the Federal agencies as they assess and mitigate seismic risks in their existing buildings. A major development in this new ICSSC standard is the adoption of national model standards for existing buildings that are developed by the American Society of Civil Engineers.

6.2 EarthScope

EarthScope is a multidisciplinary earth science program aimed at exploring in unprecedented detail the four-dimensional structure, dynamics, and evolution of the North American continent. EarthScope is supported by NSF in partnership with USGS and the National Aeronautics and Space Administration. The EarthScope program provides a framework for broad, integrated studies of fault properties and earthquake processes, and for the analysis of seismic and volcanic hazards, fluids and magma in the Earth's crust and mantle, plate-boundary processes, large-scale continental deformation, continental structure and evolution, and deep-Earth structure. EarthScope has developed the cyberinfrastructure to integrate, distribute, and analyze the diverse data sets collected by its facilities. In addition, the EarthScope Education and Outreach Program is actively engaging the general public, educators, and students to teach them about EarthScope science and to promote science literacy.

The EarthScope Facility, successfully completed in September 2008, is composed of three core components: the San Andreas Fault Observatory at Depth (SAFOD), the Plate Boundary Observatory (PBO), and the United States Seismic Array (USArray). By the end of 2011, more than 1,100 permanent GPS stations, 1,400 seismic stations, 84 strainmeters, 354 magnetotelluric stations, and 26 tiltmeters were installed in these three components, which are described below.

San Andreas Fault Observatory at Depth

SAFOD is a 3 km deep hole drilled directly into the San Andreas Fault midway between San Francisco and Los Angeles, near Parkfield, CA. Located in an area that has ruptured six times since 1857, the hole is providing the first opportunities to observe directly the conditions under which earthquakes occur, to collect rocks and fluids from the fault zone for laboratory study, and to continuously monitor the physical conditions within an active earthquake nucleation zone. Data collected by SAFOD are providing unique insights into the physical and material conditions within a zone of active faulting. Sections of material removed during the drilling have been extracted and the cores are being analyzed by the scientific community, providing insights such as the roles of different minerals and fault fluids in earthquake and faulting processes.

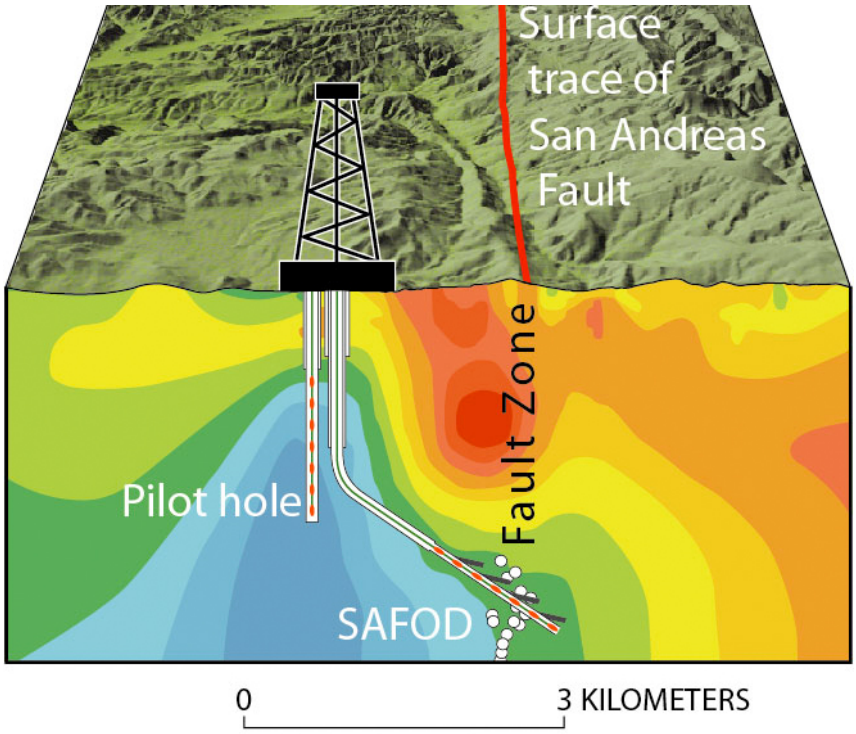


Figure 6–1. A schematic of the SAFOD facility. Image courtesy of USGS.

Plate Boundary Observatory

The PBO is a geodetic observatory designed to study the three-dimensional strain field resulting from deformation across the active boundary zone between the Pacific and North American plates in the Western United States. The observatory consists of arrays of GPS receivers and strainmeters, which are being used to deduce the strain field on time scales of days to decades, and for geologic and paleoseismic investigations to examine the strain field over longer time scales. The PBO consists of several major observatory components: a network of 1,100 permanent, continuously operating GPS stations, many of which provide data at a high rate and in real time; 78 borehole seismometers; 74 borehole strainmeters; 26 shallow borehole tiltmeters; and six long baseline laser strainmeters.

These instruments are complemented by InSAR and LiDAR imagery and geochronology. The PBO also provides comprehensive data products and data management and education and outreach services.

The PBO's regional-scale geodetic network has provided surprising new information on the Pacific-North American plate boundary, showing, for example, that extension in the Basin and Range Province is not uniform, as was once widely believed, but instead is focused near its western and eastern edges. In addition, PBO GPS measurements are being used to understand the distribution of soil moisture and snow depth, key inputs to climate models, across the Western United States, and vegetation greenness, a measure of the health of the environment and of environmental response to drought.

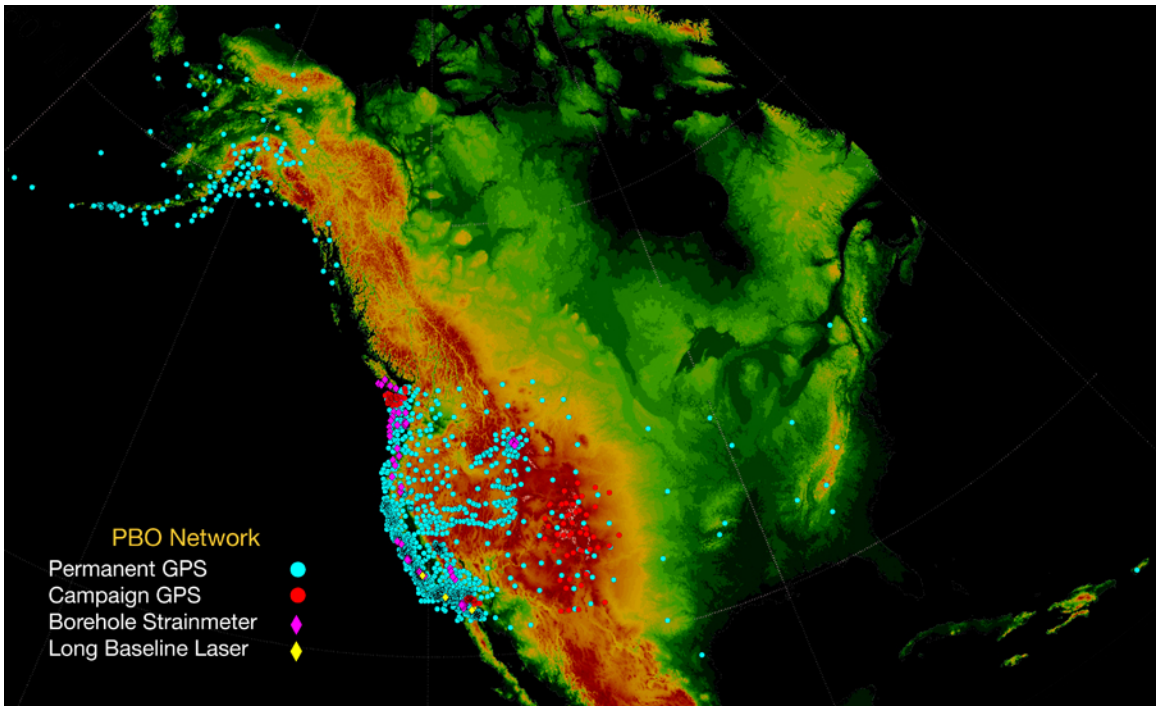


Figure 6–2. The PBO network, including the locations of GPS stations, seismometers, strainmeters, tiltmeters, and laser strainmeters. © 2012 Image Courtesy of Plate Boundary Observatory, UNAVCO Inc.

United States Seismic Array

The United States Seismic Array (USArray) is a continental-scale seismic and magnetotelluric observatory designed to provide a foundation for integrated studies of continental lithosphere and deep Earth structure over a wide range of scales. It consists of four major components: (1) a Reference Network of permanent seismic stations that forms part of the USGS ANSS, (2) a Transportable Array of about 400 seismic stations, (3) a Flexible Array pool of more than 2,000 portable seismic instruments for use in experiments proposed by individual scientists, and (4) a

Magnetotelluric Array with permanent and transportable instruments that record naturally occurring electric and magnetic fields. The Transportable Array is a rolling network of seismometers, moving from west to east across the United States, with stations spaced every 70 km. The USArray is providing new insights and data pertinent to fundamental questions about earthquake physics, volcanic processes, core-mantle interactions, active deformation and tectonics, continental structure and evolution, geodynamics, and crustal fluids (magmatic, hydrothermal, and meteoric). A map showing the locations of array instruments, which is regularly updated as mobile resources move, is available at www.usarray.org/status.

6.3 Next Generation Attenuation Relationships for Central and Eastern North-America (NGA-East)

NGA-East is a multi-disciplinary research project coordinated by the Pacific Earthquake Engineering Research center (PEER), with headquarters at the University of California, Berkeley. The project involves a large number of participating researchers from various organizations in academia, industry and government. The project is jointly sponsored by the U.S. Nuclear Regulatory Commission (NRC), the U.S. Department of Energy (DOE), the Electric Power Research Institute (EPRI) and the U.S. Geological Survey (USGS). The objective of NGA-East is to develop a new ground motion characterization (GMC) model for the Central and Eastern North-American (CENA) region. The GMC model consists in a set of new ground motion prediction equations (GMPEs) for median and standard deviation of ground motions (GMs) and their associated weights in the logic-trees for use in probabilistic seismic hazard analyses (PSHA).

6.4 Subcommittee on Disaster Reduction

The Subcommittee on Disaster Reduction (SDR) is an element of the President's National Science and Technology Council that facilitates the development of national strategies for reducing disaster risks and losses that are based on effective use of science and technology. Mitigating natural and technological disasters requires a solid understanding of science and technology, rapid implementation of research information into disaster reduction programs and applications, and efficient access to diverse information available from both public and private entities. Chartered in 1988, the SDR provides a unique Federal forum for information sharing; the development of collaborative opportunities; the formulation of science- and technology-based guidance for policy makers; and dialogue with the U.S. policy community to advance informed strategies for managing disaster risks.

Representatives of NEHRP participate in SDR meetings and provide briefings on program developments. The SDR serves as a forum that NEHRP agencies can use for reaching out to and coordinating with other Federal agencies doing work related to NEHRP goals and objectives.

6.5 International Activities

U.S.-Japan Cooperative Program on Natural Resources

In 1964, the United States and Japan established the U.S.-Japan Cooperative Program on Natural Resources (UJNR) to promote bilateral cooperation in research and data exchange. Today, the UJNR involves 18 U.S. agencies and 10 Japanese agencies. The NEHRP agencies play important roles in the UJNR panels on earthquake research and on wind and seismic effects. The U.S. sides of these panels are chaired by USGS and NIST, respectively.

U.S.-Japan Panel on Earthquake Research

USGS made plans to host a meeting of the UJNR Panel on Earthquake Research near Denver, CO, in early October 2012. Topics to be discussed at this meeting include the following: advantages and limitations of cluster analysis in interpreting regional GPS velocity fields in California and elsewhere; real-time earthquake magnitude estimates and rapid rupture characterization from real-time GPS; and U.S. national seismic hazard maps and urban seismic hazard maps based on three-dimensional simulations.

U.S.-Japan Panel on Wind and Seismic Effects

The UJNR Panel on Wind and Seismic Effects did not meet during 2012. A meeting was held at NIST February 20-21, 2013. Task committees of the panel conducted workshops on bridge engineering and on structural dynamics and monitoring of bridges and flexible structures against wind hazards.

U.S.-China cooperation in earthquake studies

The United States-China program saw continued scientific cooperation on several fronts, including both seismology and engineering. Negotiations were completed for a thorough upgrade (by 2014) of the China-United States broadband digital seismic array that consists of 10 high-quality seismic observatories distributed throughout China. Analysis of geophysical data from the 2008 Wenchuan earthquake that claimed approximately 80,000 lives continued, and included the completion of a detailed analysis of GPS and strong ground motion data.

A Chinese research program was initiated to collect LiDAR data over selected regions in China with high seismic hazards, with USGS providing training in LiDAR data acquisition and processing during exchange visits. The first results from this important program have been published and have attracted considerable interest in both countries. With support from NSF and the National Natural Science Foundation of China, the Third Workshop on China-U.S. Collaboration for Disaster Evolution/Resilience of Civil Infrastructure and Urban Environment was held at UC Berkeley, where Chinese and U.S. researchers discussed opportunities for research collaboration.

NEES sharing results and facilities with foreign interests

NSF's "Memorandum Concerning Cooperation in the Area of Disaster Prevention Research" with Japan's Ministry of Education, Culture, Sports, Science, and Technology enables U.S. researchers to use both NEES facilities and Japan's E-Defense shake table, the world's largest, to investigate the seismic performance of large- to full-scale geotechnical and structural innovations. To enable this collaboration, data sharing, and joint use of facilities, Purdue University, through the NEES operations award from NSF, has established a partnership with Japan's National Research Institute for Earth Science and Disaster Prevention, which operates the E-Defense shake table facility. Annual workshops are organized through an NSF award to UC Berkeley for coordination of the NEES/E-Defense collaborative research program in earthquake engineering. As part of NEES operations for fostering additional international collaborations, Purdue has also formalized partnerships with the Port and Airport Research Institute in Japan; the Canadian Seismic Research Network, which is headquartered at McGill University in Montreal, Quebec, Canada; and Tongji University in China.

Appendix A
Cooperating Organizations Receiving NEHRP Support

NEHRP provided partial support in the form of either contracts or financial assistance for the following organizations, either directly or through a recipient, to advance NEHRP goals and objectives. This listing does not include the many academic institutions to which NEHRP provides individual research grants and cooperative agreements. For each organization that is presented, a link to its website is provided.

Applied Technology Council (ATC)

The Applied Technology Council is a nonprofit corporation established in 1973 through the efforts of the Structural Engineers Association of California. ATC's mission is to develop and promote state-of-the-art, user-friendly engineering resources and applications for use in mitigating the effects of natural and other hazards on the built environment. ATC also identifies and encourages needed research and develops consensus opinions on structural engineering issues in a nonproprietary format. Project work is conducted by a wide range of highly qualified consulting professionals, thus incorporating the experience of many individuals from academia, research, and professional practice who would otherwise not be available from any single organization. Funding for ATC projects is obtained from government agencies and from the private sector. More information about ATC is available at www.atcouncil.org.

Consortium of Universities for Research in Earthquake Engineering (CUREE)

CUREE is a nonprofit organization, established in 1988, that is devoted to the advancement of earthquake engineering research, education, and implementation. CUREE's membership, comprising some two dozen universities and many associated faculty members, works to identify new ways that research can solve earthquake problems; to collect and synthesize information and make it easily accessible; to establish national and international hazard research relationships; to perform earthquake engineering and related research; to manage research consortia and cooperative programs; and to educate experts, practitioners, students, and the public. More information about CUREE is available at www.curee.org.

Earthquake Engineering Research Institute (EERI)

EERI is the Nation's leading technical society dedicated to the reduction of risk from earthquakes and is recognized as an authoritative voice for earthquake risk reduction information in the United States. It is a national, nonprofit, multidisciplinary technical society of engineers, geoscientists, architects, planners, public officials, and social scientists. EERI is a membership organization that currently has chapters throughout the United States, including many student chapters at universities.

Its mission is to reduce earthquake risk by (a) advancing the science and practice of earthquake engineering, (b) improving understanding of the impact of earthquakes on the physical, social, economic, political, and cultural environment, and (c) advocating for comprehensive and realistic measures for reducing the harmful effects of earthquakes. EERI engages in many activities to help Federal agencies implement their unique NEHRP responsibilities. These include producing technical publications and seminars, conducting multidisciplinary post-earthquake investigations, and providing support and hands-on learning experiences to students, among many others. More information about EERI is available at www.eeri.org.

Federal Alliance for Safe Homes (FLASH®)

FLASH is a nonprofit organization that advocates on behalf of consumers for strengthening homes and safeguarding families from natural and man-made disasters. FLASH entered into a cooperative agreement to help NEHRP and the FEMA Building Science Branch achieve their program-related goals, and completed five projects in 2012. More information about FLASH is available at www.flash.org.

First, FLASH promoted FEMA's *QuakeSmart Toolkit* (FEMA P–811CD) to more than 150 associations in 18 states, educating more than 14,000 small business owners on structural and nonstructural mitigation. Second, FLASH developed four new consumer resources, including three FLASH Cards (Prepare Your Family, Protect Your Home, and Protect Your Contents) and one nonstructural "how-to" animation to help businesses prepare their employees, their employees' families, and their communities for seismic events. These resources, as well as the *QuakeSmart Toolkit,* were translated into Spanish. Third, in partnership with the Los Angeles County Fire Department, FLASH piloted a nonstructural assessment program to embed mitigation into annual small-business fire inspections. The results of more than 30 pilot inspections will help FLASH design a statewide program in 2013. Fourth, FLASH surveyed how building code courses are currently taught in universities and colleges across the Nation. Based on the survey results and subsequent interviews, FLASH created two model university courses that will be released in 2013. Finally, FLASH developed MitigationMovement.org to share education campaigns, academic research, technical resources, and long-term recovery information among mitigation stakeholders. This "open source" site will be implemented in 2013 and will include more than 900 organizations.

Incorporated Research Institutions for Seismology (IRIS)

IRIS is an NSF-supported consortium of over 100 U.S. universities dedicated to the operation of science facilities for the acquisition, management, and distribution of seismological data. IRIS partners with USGS in the operation of the GSN, which provides data for global seismological research and is one of the primary data sources used by the USGS NEIC in tracking global earthquake activity. The IRIS Program for Array Seismic Studies of the Continental Lithosphere loans portable seismograph systems for national and international field investigations, including many that have contributed to studies of earthquakes and earth structure under NEHRP. The IRIS Education and Outreach Program enables audiences beyond seismologists to access and use

seismological data and research for educational purposes. The IRIS USArray (part of the NSF-funded EarthScope project) includes permanent stations that have contributed to the USGS ANSS as well as portable stations that are systematically collecting data from across the continental United States.

Data collected by all of these IRIS programs are assessed, archived, and distributed through the IRIS Data Management System, along with data contributed from numerous national and international sources, including ANSS, U.S. regional networks, and other NEHRP programs. More information about IRIS is available at www.iris.edu.

National Institute of Building Sciences (NIBS)

Congress chartered NIBS in 1974 as an independent, nongovernmental, nonprofit organization. NIBS balances public and private expertise to mobilize uniquely authoritative support for the public interest in building sciences, engineering, construction, and technology. NIBS involves the national building community in shaping its programs and priorities through its Consultative Council; other councils address specific issues in security and disaster preparedness, facility performance and sustainability, and information resources and technologies. More information about NIBS is available at www.nibs.org.

Since 1979, the Building Seismic Safety Council (BSSC) of NIBS has provided a national forum for improving earthquake-resistant design and construction, benefiting both the building community and the public in general. Its fundamental purpose is to enhance public safety by providing a national forum that fosters improved seismic safety provisions for use by the building community in the planning, design, construction, regulation, and utilization of buildings. More information about the BSSC is available at www.nibs.org/?page=bssc.

Natural Hazards Center

The Natural Hazards Center at the University of Colorado at Boulder serves as a national and international clearinghouse of knowledge concerning the social science and policy aspects of disasters. The center collects and shares research and experience related to preparedness for, response to, recovery from, and mitigation of disasters, emphasizing the link between hazard mitigation and sustainability. A basic goal of the center is to strengthen communication among researchers and the individuals, organizations, and agencies concerned with reducing damage caused by disasters. NSF, USGS, and other Federal agencies support the Natural Hazards Center. Using an all-hazards and interdisciplinary framework, the center fosters information sharing and integration of activities among researchers, practitioners, and policy makers from around the world; supports and conducts research; and provides educational opportunities for the next generation of hazards scholars and professionals.

The center's products include the *Natural Hazards Observer* newsletter; one of the most widely used websites in the hazards field (www.colorado.edu/hazards/); the biweekly electronic newsletter

Disaster Research; a listserv for student researchers; the American Society of Civil Engineers journal *Natural Hazards Review,* which is co-edited by the center director; and monographs and special publications. The center also provides library and information services, and center feeds are available on Twitter at HazCenter. The 38th Annual Natural Hazards Research and Applications Workshop, to be held July 13–18, 2013, in Broomfield, CO, will bring together researchers and practitioners from many disciplines for face-to-face discussions on how society deals with hazards and disasters. More information about the Natural Hazards Center is available at www.colorado.edu/hazards/.

Southern California Earthquake Center (SCEC)

SCEC, headquartered at the University of Southern California, was founded in 1991 with a mission to gather data on earthquakes in southern California and elsewhere, to integrate information into a comprehensive and physics-based understanding of earthquake phenomena, and to communicate that understanding to society at large as useful knowledge for reducing earthquake risk. A community of over 600 scientists from 16 core institutions, 47 participating institutions, and elsewhere participates in SCEC. The center also partners with a large number of other research, education, and outreach organizations in many disciplines. In 2012, the center completed its third phase, SCEC3 (a 5-year program funded by NSF and USGS), and launched its fourth 5-year phase, SCEC4, with an ambitious research and outreach agenda.

To support its community of participating organizations, SCEC engages in information technology research that will revolutionize our methods of doing collaborative research and distributing research products online. In addition, the SCEC Communication, Education, and Outreach Program offers research experiences to students, web-based education tools, classroom curricula, museum displays, public information brochures, online newsletters, and technical workshops and publications. More information about SCEC is available at www.scec.org.

Regional Earthquake Consortia

Cascadia Region Earthquake Workgroup (CREW)

CREW is a coalition of private and public representatives working together to improve the ability of communities throughout the Cascadia Region (northern California, Oregon, Washington, and British Columbia) to reduce the effects of earthquakes and related hazards, such as tsunamis. Since the mid-1990s, CREW has created several publications, including scenarios, post-disaster recovery guides, and other educational materials accessible on CREW's website (http://crew.org/). CREW is composed of mostly volunteer representatives that help foster linkages between scientists, businesses, and government agencies to promote earthquake resiliency. CREW, the newest of the regional earthquake consortia, is now halfway through its 5-year strategic plan.

CREW held a series of business roundtables in 2012 in Portland, Seattle, and Vancouver, B.C. The objectives of the roundtables were to further develop interaction between CREW and the business community; provide a setting in which businesspeople could discuss their concerns about and current levels of earthquake preparedness; and allow CREW to learn from the participants about the

types of tools and information CREW can supply that would be of greatest use to businesses. CREW intends to use the results of the roundtables to further develop and improve the focus of the information and other resources it offers to the business community. The more prepared businesses are to withstand and recover quickly from the next big earthquake, the greater will be the resilience of the regional economy and of every community that depends on it.

CREW organized and hosted three public forums about current research and events related to the earthquake hazard. The topics addressed were as follows: "What Tohoku Teaches Us About Cascadia" (Portland); "Advancements in Pacific Northwest Earthquake Hazard Understanding" (Seattle); and "School Seismic Safety" (Vancouver, B.C.).

CREW completed six webcasts, many of which are located on CREW's YouTube site. These webcasts will be used in the upcoming year to develop mitigation and resilience video clips that will be published on the CREW website and geared to businesses and the public. CREW's website is its main source for distributing information on earthquake preparedness, planning, and mitigation. The website was updated to ensure that CREW was reaching its target audiences. Updates are continuing this year as CREW develops new material

CREW began updating the 2005 Cascadia Subduction Zone Scenario document. Recently, FEMA began a catastrophic planning effort for Pacific Northwest communities, focused on a Cascadia Subduction Zone earthquake. This effort includes updated ground motion and tsunami models, infrastructure inventories, and HAZUS modeling. The results of this effort will be used as a basis for the update to the CREW scenario.

Central United States Earthquake Consortium (CUSEC)

CUSEC (www.cusec.org/) was established in 1983. The CUSEC Board of Directors includes the heads of the emergency management agencies of the eight member states: Alabama, Arkansas, Illinois, Indiana, Kentucky, Mississippi, Missouri, and Tennessee. Ten associate states represented in FEMA Regions IV, V, VI, and VII also participate: Georgia, Iowa, Kansas, Louisiana, Nebraska, North Carolina, Ohio, Oklahoma, South Carolina, and Virginia. CUSEC projects in 2012 related to public awareness and education, mitigation, response and recovery, and the application of research.

In the awareness arena, CUSEC hosted three town hall meetings; created and distributed brochures and newsletters; continued its GeoCache initiative (500 visitors); conducted and supported Earthquake Awareness Month with CUSEC states; briefed the Congressional Natural Hazards Caucus; and coordinated key events, including the 1811–1812 New Madrid Earthquake Bicentennial events, the Great Central U.S. ShakeOut (2.4 million participants), and the National Earthquake Conference. CUSEC also was the recipient of the 2011 White House Champions of Change Award (Brian Blake) and a 2011 FEMA Individual and Community Preparedness Award.

CUSEC conducted three FEMA 154/ATC–20 courses, a *Get Your Home Ready for Earthquakes* seminar, and two hospital mitigation workshops, and created a display on nonstructural mitigation for home owners. Response and recovery activities included work with USGS and state geologists to

develop better response and recovery plans. CUSEC also is supporting the CAPSTONE–14 planning and preparedness effort, and hosted a workshop for the private sector and emergency management community in the Chicago area on how the two sectors can better work together. Research application projects focused on integrating new hazards information into the consortium's earthquake messaging and working with state geological surveys and USGS to support national response planning.

In partnership with Virginia, Maryland, the District of Columbia, FEMA, the National Park Service, and USGS, CUSEC had a leadership role in a press conference held on August 23, 2012, at the Washington Monument to mark the one-year anniversary of the Mineral, VA, earthquake that shook much of the East Coast. The press conference also served as the kick-off event for the National Preparedness Month and Great SouthEast ShakeOut initiatives. Senior Federal officials and officials from Maryland and the District of Columbia spoke at the press conference. Topics addressed included ongoing challenges to the earthquake recovery, current knowledge of the earthquake threat, and public preparedness programs for protecting lives and saving property. The press conference was covered by *USA Today,* CNN, NBC Nightly News, CBS Evening News, the Associated Press, and more than a dozen other media outlets.

Northeast States Emergency Consortium (NESEC)

NESEC (www.nesec.org/) was established in 1991 and is located in Wakefield, MA. The consortium develops, promotes, and coordinates comprehensive "all-hazards" emergency management activities throughout the Northeast. This work encompasses all phases of emergency management: preparedness, response, recovery, and mitigation. NESEC's work is a vital component of planning and response efforts focused on the safety and welfare of the more than 40 million people living in the Northeast states. NESEC comprises the member States of Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont.

An important project completed by NESEC was the URM Building Inventory and Mitigation Strategy. This is a new mapping technology for raising awareness of the number, locations, and types of unreinforced masonry (URM) buildings in the region and the mitigation strategies available for them. Many of the URM buildings in the Northeast are in urban areas, from Boston to New York City. Project results indicate that there are an estimated 1.6 million URM buildings in the Northeast (16,240 in Boston based on HAZUS data and 18,919 in Boston based on data from parcel maps—an 86 percent agreement between HAZUS and the parcel maps). The results demonstrate that the HAZUS data is reasonable and supported by parcel maps, and that Google Maps can serve as validation tools.

Western States Seismic Policy Council (WSSPC)

WSSPC was established in 1979. The 39 agency members of WSSPC include the directors of the geological surveys and emergency management agencies from 13 Western states, British Columbia, the Yukon Territory, American Samoa, Guam, and the Northern Mariana Islands, plus representatives from seven seismic councils and commissions. Affiliate members include private

corporations, local governments, nonprofit organizations, universities, and individuals who share the common goal of reducing losses from earthquakes. Approximately 84 percent of the significant seismic risk in the United States is located in the WSSPC region.

The primary work of WSSPC is developing policy recommendations via three standing committees: the Basin and Range Province Committee; the Tsunami Hazard Mitigation Committee; and the Committee for Engineering, Construction, and Building Codes. To date, 15 policy recommendations have been developed by WSSPC, all of which are posted on the WSSPC website, and updated versions of 9 policies will be discussed and adopted by members in 2013. These nine policies focus on new and existing schools, tsunamis, post-earthquake clearinghouses and information management systems, building codes, hazard assessments, and earthquake early warning.

The WSSPC Awards in Excellence program has been in effect since 1996 to recognize exemplary programs, projects, or products that have contributed to earthquake risk reduction through demonstrated achievements. The Oregon Seismic Rehabilitation Grant Program won the 2013 Overall Award in Excellence. Other programs, projects, and products that received 2013 awards are Oregon DOGAMI Special Publication 43 (*Simulating Tsunami Inundation at Bandon, Coos County, Oregon, Using Hypothetical Cascadia and Alaska Earthquake Scenarios*), the Pacific Earthquake Engineering Research Center's Tall Buildings Initiative, the Washington School Seismic Safety Assessment Pilot Project, and the Resilient Washington State Initiative. These awards are highlighted on the WSSPC website (www.wsspc.org) where others are encouraged to transfer, adapt, and adopt these programs. Quarterly newsletters, a membership roster, press releases, information on the status of building code adoptions, and links to state hazard mitigation plans are other features of the WSSPC website.

Appendix B
List of Acronyms and Abbreviations

ACEHR	Advisory Committee on Earthquake Hazards Reduction
ANSS	Advanced National Seismic System
ARRA	American Recovery and Reinvestment Act
ASHSC	Alaska Seismic Hazard Safety Commission
ATC	Applied Technology Council
BCEGS	Building Code Effectiveness Grading Schedule
BSSC	Building Seismic Safety Council
Cal VIVA	California Vital Infrastructure Vulnerability Assessment
Caltech	California Institute of Technology
CREW	Cascadia Region Earthquake Workgroup
CUREE	Consortium of Universities for Research in Earthquake Engineering
CUSEC	Central United States Earthquake Consortium
DOE	U.S. Department of Energy
DOGAMI	Oregon Department of Geology and Mineral Industries
EAEHMP	Evansville (IN) Area Earthquake Hazards Mapping Project
ECA	Earthquake Country Alliance
EERI	Earthquake Engineering Research Institute
EMI	Emergency Management Institute
FEMA	Federal Emergency Management Agency
FLASH	Federal Alliance for Safe Homes
FY	Fiscal year
GEER	Geotechnical Extreme Events Reconnaissance
GSN	Global Seismographic Network
HSEAC	Hawaii State Earthquake Advisory Committee
ICC	(NEHRP) Interagency Coordinating Committee
ICSSC	Interagency Committee on Seismic Safety in Construction
IEMA	Illinois Emergency Management Agency
InSAR	Interferometric synthetic aperture radar
IRIS	Incorporated Research Institutions for Seismology
ISO	Insurance Services Office
km	Kilometer
LiDAR	Light detection and ranging

NEES	George E. Brown, Jr. Network for Earthquake Engineering Simulation
NEHRP	National Earthquake Hazards Reduction Program
NEIC	National Earthquake Information Center
NESEC	Northeast States Emergency Consortium
NETAP	National Earthquake Technical Assistance Program
NGA	Next generation attenuation
NIBS	National Institute of Building Sciences
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NSF	National Science Foundation
NSL	Nevada Seismological Laboratory
NSMP	National Strong-Motion Project
OEM	(Oregon) Office of Emergency Management
OSSPAC	Oregon Seismic Safety Policy Advisory Commission
PACT	Performance Assessment Calculation Tool
PBO	Plate Boundary Observatory
PBSD	Performance-based seismic design
PCWG	(NEHRP) Program Coordination Working Group
PL	Public law
PNSN	Pacific Northwest Seismic Network
RAPID	Rapid Response Research
REU	Research Experiences for Undergraduates
ROVER	Rapid Observation of Vulnerability and Estimation of Risk
SAFOD	San Andreas Fault Observatory at Depth
SBA	U.S. Small Business Administration
SCEC	Southern California Earthquake Center
SDR	Subcommittee on Disaster Reduction
SEAU	Structural Engineers Association of Utah
SSC	(Washington State) Seismic Safety Committee
STEM	Science, technology, engineering, and mathematics
SURE	Summer Undergraduate Research Experiences
UC	University of California
UCERF	Uniform California Earthquake Rupture Forecast
UJNR	U.S.-Japan Cooperative Program on Natural Resources
UNLV	University of Nevada Las Vegas
URM	Unreinforced masonry
USArray	United States Seismic Array

UseIT	Undergraduate Studies in Earthquake Information Technology
USGS	U.S. Geological Survey
USSC	Utah Seismic Safety Commission
VA	U.S. Department of Veterans Affairs
WGCEP	Working Group on California Earthquake Probabilities
WSSPC	Western States Seismic Policy Council