Annual Report of the National Earthquake Hazards Reduction Program

For Fiscal Year 2015

March 2018

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 (FY) 2015 is submitted to Congress by the Interagency Coordinating Committee of NEHRP, as required by the Earthquake Hazards Reduction Act of 1977 (Public Law 95-124, 42 U.S.C. 7701 *et. seq.*), as amended by the Earthquake Hazards Reduction Program Reauthorization Act of 2004 (Public Law 108-360).

The members of the Interagency Coordinating Committee as of May 27, 2018, are as follows:

Chair
Dr. Walter Copan
Under Secretary of Commerce for Standards and Technology and Director
National Institute of Standards and Technology
U.S. Department of Commerce

Mr. William B. "Brock" Long
Administrator
Federal Emergency Management Agency
U.S. Department of Homeland Security

Dr. France A. Córdova
Director
National Science Foundation

Mr. John Michael "Mick" Mulvaney
Director
Office of Management and Budget
Executive Office of the President

Mr. Michael Kratsios
Deputy Assistant to the President for Science and Technology and Deputy
U.S. Chief Technology Officer
Office of Science and Technology Policy
Executive Office of the President

Dr. James F. Reilly II
Director
U.S. Geological Survey
U.S. Department of the Interior

Disclaimer: Certain trade names or company products are mentioned in the text to adequately specify the experimental procedures and equipment used. In no case does such identification imply recommendation or endorsement by any of the agencies represented on the Interagency Coordinating Committee, 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) covering FY 2015,[1] presented by the NEHRP Interagency Coordinating Committee. This report, required by Public Law 108–360, describes the FY 2015 activities of the NEHRP agencies and their progress toward reducing the impacts of future earthquakes in the United States. This report also summarizes actual program budgets for FY 2016 and budgets requested by the Administration for FY 2017.

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. The NEHRP agencies have distinct roles and responsibilities that are mutually supportive.

The NEHRP Interagency Coordinating Committee 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 (OSTP) and Office of Management and Budget (OMB). The Director of NIST chairs the Interagency Coordinating Committee.

In FY 2015, there were 19 earthquakes worldwide with a magnitude of 7.0 (M7.0) or higher. These earthquakes caused 9,612 deaths; this was a significant increase compared with the 664 earthquake-related deaths in 2014. Moreover, a M7.8 earthquake occurred on April 25 in Nepal for which 8,964 fatalities were attributed. It was followed by an M7.3 aftershock on May 12 that killed an additional 218 people. An estimated 500,000 structures were destroyed and another 269,000 were damaged in this event, totaling $5 billion in damages. The severe consequences of this earthquake triggered broad international response and recovery efforts to provide immediate aid, as well as interim food, shelter, and other necessities. Additionally, a wide range of post-earthquake activities and investigations were carried out by the NEHRP agencies.

Deadly earthquakes also occurred in Afghanistan and Chile. In the central U.S., seismicity continued to increase in 2015, with 32 earthquakes of M4.0 and greater in Kansas, Oklahoma, and Texas, compared with 17 in 2014, and the USGS recorded over a thousand earthquakes above M3.0 in this region. Most, if not all, of these events were induced by the injection disposal into underground rock formations of wastewater used in or produced by oil and gas recovery operations. This wastewater consists of saltwater produced along with the oil and gas, and with fluids used in hydraulic fracturing.

[1] This report covers FY 2015 as defined by the Federal Government, a period that began on October 1, 2014, and ended on September 30, 2015.

A primary role of NEHRP is to provide leadership and resources for developing new, cost-effective measures to reduce the damage and disruption that earthquakes cause, and to advocate for their implementation. Some of the significant NEHRP activities of FY 2015 that are covered in this report are listed briefly below.

In support of NEHRP Strategic Plan Goal A, *Improve Understanding of Earthquake Processes and Inputs*, the NSF-sponsored Geotechnical Extreme Events Reconnaissance (GEER) Association and the USGS Earthquake Disaster Assistance Team (EDAT) sent experts to provide technical assistance after the Nepal earthquake, and to collect perishable data that were critical to understanding the earthquake and its impacts. The NSF Decision Frameworks for Multi-Hazard Resilient and Sustainable Buildings solicitation resulted in four new research projects, $4.92 million in total funding, awarded to multidisciplinary teams across eight universities to improve the design of resilient and sustainable buildings. Research continues to test the performance of tall timber buildings in seismic events. A new USGS report was released that describes, for the first time, how injection-induced earthquakes can be incorporated into U.S. seismic hazard models, and methods and procedures were developed for issuing aftershock forecasts on-demand following large earthquakes anywhere in the U.S. or abroad.

In support of NEHRP Strategic Plan Goal B, *Develop Cost-Effective Measures to Reduce Earthquake Impacts on Individuals, the Built Environment, and Society at Large*, USGS experts worked with the building design community to adopt the 2014 update to the USGS National Seismic Hazard Maps into engineering design maps and building codes. The new seismic hazard estimates provide improved estimates of the likelihood of ground shaking during the lifespan of buildings, bridges, and other structures. NSF supported an award for Small Business Innovation Research (SBIR) focused on providing software tools for the rapid calculation of structural performance and damage during an earthquake and repair costs for high-performance building design. NIST supported the production of *NEHRP Seismic Design Technical Brief 11, Seismic Design of Steel Buckling-Restrained Braced Frames: A Guide for Practicing Engineers* by the Applied Technology Council (ATC), which provides state-of-the-art guidance to practicing engineers. Performance-based seismic design (PBSD) has emerged as an effective means of designing structures to resist earthquake ground motions while allowing structural engineers more latitude in their design approaches. NIST concluded a five-year study of first generation PBSD approaches to determine how well buildings designed using PBSD would perform in contrast to buildings designed using prescriptive methods. FEMA also produced technical guidance for buildings, including the 2015 edition of the *NEHRP Recommended Seismic Provisions for New Buildings and Other Structures* (*NEHRP Recommended Provisions*) and FEMA P-1026 *Seismic Design of Rigid Wall-Flexible Diaphragm Buildings: An Alternate Procedure.*

The USGS partnered with FEMA to provide earthquake scenarios and seismic hazard and risk information for public earthquake safety exercises, and continued to support ShakeOut, the world's largest earthquake preparedness drill. USGS also made significant progress developing its ShakeAlert research project into an operational earthquake early warning (EEW) system for the

West Coast. USGS provided funding for research grants and cooperative agreements with universities, State agencies, and private technical firms for research and monitoring. Additionally, NSF supported several initiatives that enhance education and training for future researchers and practitioners in the earthquake and other hazards fields.

Support continues for important facilities that coordinate and modernize earthquake monitoring. Thanks to substantial improvements to station coverage and methods for rapid analysis, the Advanced National Seismic System (ANSS) now typically reports on domestic earthquakes within minutes of their occurrence. To support partner activities in earthquake monitoring in 2015, approximately $6.6 million was provided through cooperative agreements for regional seismic and geodetic networks, and structural and geotechnical arrays. The Global Seismographic Network (GSN) consists of 150 stations worldwide and the USGS continued to lead a multi-agency effort to develop and procure new borehole sensors, as part of ongoing efforts to maintain and improve the GSN.

NSF launched a new Natural Hazards Engineering Research Infrastructure (NHERI) described as the next generation of NSF support for a multi-user, natural hazards engineering research facility, replacing the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) during FY 2015. NHERI is a national facility that provides the natural hazards engineering community with access to research infrastructure, coupled with education and community outreach activities. NHERI will enable the natural hazards engineering community to make research and educational advances collaboratively that can contribute knowledge and innovation to prevent natural hazards from becoming societal disasters. Several awards were made in FY 2015 for NHERI.

Section 1

Introduction

The National Earthquake Hazards Reduction Program (NEHRP) is a four-agency program established by Congress "to reduce the risks of life and property from future earthquakes in the United States."[2] 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 United States Geological Survey (USGS). NIST serves as the lead agency.

Congress has periodically reauthorized the program, generally at two- to five-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 FY 2009. Pending passage of new reauthorizing legislation, the NEHRP agencies continue to perform duties outlined in Public Law 108–360 within agency-established budget allocations.

Public Law 108–360 requires that the NEHRP Interagency Coordinating Committee, through which agency directors direct the program, submit an annual report to Congress on NEHRP budgets and activities. The Interagency Coordinating Committee is submitting this annual report, covering FY 2015, pursuant to that requirement.

The FY 2015 NEHRP annual report provides an overview of NEHRP agency budgets, highlights of statutory program activities, State activities promoting implementation of research results, and a summary of non-NEHRP related activities that support NEHRP goals. This report and prior NEHRP annual reports are available at www.nehrp.gov/about/reports.htm.

In April 2015, a M7.8 earthquake struck Nepal. Over 9,000 people were killed and 17,000 injured by this earthquake and its aftershocks. An estimated 500,000 structures were destroyed and another 269,000 were damaged. The severe consequences of this earthquake triggered broad international response and recovery efforts to provide immediate aid and interim food, shelter and other necessities. A wide range of post-earthquake activities and investigations were carried out by the NEHRP agencies to provide technical assistance and collect important perishable data. Deadly earthquakes also occurred in Afghanistan and Chile in 2015. Events such as these, while deadly and destructive, provide opportunities to observe and document impacts, and help the earthquake community increase preparedness for, and resiliency to, future events. Specifically, data collection

[2] The Earthquake Hazards Reduction Act of 1977 (Public Law 95-124, 42 U.S.C. 7701 *et seq.*), as amended by Public Laws 101-614, 105-47, 106-503, and 108-360. See http://www.nehrp.gov/about/PL108-360.htm.

coupled with research informs the development of infrastructure and buildings that are resilient to earthquake hazards.
The advancement of knowledge on effective mitigation techniques for earthquakes in 2015 was coupled with the advancement of science for determining earthquake risk. Induced seismicity continues to increase earthquake risk in portions of the U.S., and progress has been made to effectively incorporate injection-induced earthquake risk into seismic hazard models. Modeling efforts for aftershock forecasting have also improved, which in turn improves preparedness and response activities. Such developments are imperative as more than 143 million Americans living in the 48 contiguous States are exposed to potentially damaging ground shaking from earthquakes.

The National Seismic Hazard Assessment was updated in 2015, providing improved estimates of the likelihood of ground shaking during the lifespan of buildings, bridges, and other structures. USGS experts worked with the building design community and engineering groups to adopt new seismic hazard estimates into engineering design maps and building codes.

Additional efforts in 2015 focused on applying research and mitigation strategies to improve national and international public safety through public earthquake safety exercise development, ShakeOut earthquake preparedness drill promotion, and further expansion of the earthquake early warning (EEW) "ShakeAlert" public alert system. Congress enacted an increase of $5.0 million to the USGS for EEW, which was used to expand seismic network coverage that is needed to ensure accurate alerts, integrate real-time Global Positioning System (GPS) data, and bolster partner activities with multiple universities to advance the system towards fully functioning as a public alert system.

As has been stated in previous NEHRP annual reports, future earthquakes in the U.S. are inevitable. The activities coordinated by NEHRP are essential for the Nation to prepare for their eventual occurrence, to prepare individuals for safely surviving them, and to mitigate their impacts on life, property, and economic and social systems. These activities are needed to support the Nation's efforts to become earthquake-resilient.

Section 2
Program Budgets

Public Law 108–360 requires that NEHRP annual reports include, for each agency participating in the program and for each program activity defined in the legislation, the budget for the current FY (i.e., the year following that which was covered in the report) and the proposed program budget for the next FY. *See* 42 U.S.C. § 7704(a)(4). The *Strategic Plan for the National Earthquake Hazards Reduction Program, Fiscal Years 2009–2013* (http://nehrp.gov/pdf/strategic_plan_2008.pdf), published in October 2008[3], defined three major goals for NEHRP that encompass all but one of the program activities defined in Public Law 108–360. The remaining activity, which concerns 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.

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, and local governments, and others.
Develop, operate, and maintain NEHRP facilities.	Develop, operate, and maintain ANSS, NHERI, and the GSN.

*As defined by Congress in Public Law 108–360.

Program agency budgets for FY 2015 were presented in Table 2.2 of the FY 2014 NEHRP Annual Report (see https://nehrp.gov/pdf/2014NEHRPAnnualReport.pdf). Program agency budgets for

[3] The Strategic Plan continues to be relevant and remains in effect. It will be updated in accordance with the provisions of any future NEHRP reauthorization, or as future need for additional strategic planning may dictate.

FY 2016 are presented in Table 2.2, which shows the funding that each participating agency used to accomplish the goals and objectives specified in the strategic plan. Table 2.3 identifies the agency funding requested or anticipated for NEHRP in FY 2017. Funding for the development, operation, and maintenance of NEHRP facilities supports the ANSS and the GSN.

2.1 NEHRP Enacted FY 2016 Budgets by Strategic Goal

Table 2.2 lists the FY 2016 NEHRP budgets, by strategic goal, for the NEHRP agencies: FEMA, NIST, NSF, and USGS.

Table 2.2 – *NEHRP AGENCY BUDGETS for FY 2016*

Strategic Goal	FY 2016 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	50.7	11.6	**62.7**
Goal B: Develop cost-effective measures to reduce earthquake impacts on individuals, the built environment, and society at large.	4.6	4.6		2.4	**11.6**
Goal C: Improve the earthquake resilience of communities nationwide.	3.8	0.3		16.3	**20.4**
Develop, operate, and maintain NEHRP facilities:					
ANSS				30.2	**30.2**
GSN			3.5	6.5	**10.0**
Total:	**8.5**	**5.2**	**54.2**	**67.0**	**134.9**

Notes on Table 2.2:

[1] Enacted budgets are rounded to the nearest $0.1 million (M). FEMA and NIST budgets are those agencies' allocations for NEHRP activities from total agency appropriations. NSF budget is its expenditure for NEHRP activities from total agency appropriations. USGS budget is the amount appropriated for USGS NEHRP activities.

[2] FEMA FY 2016 budget supported all NEHRP-related activities, including employee salaries and expenses (S&E).

[3] NIST FY 2016 budget supported all NEHRP-related activities, including NEHRP Secretariat (Lead Agency) and NIST Earthquake Risk Reduction in Buildings and Infrastructure research and development (R&D) Program activities. Budget included $1.3M of new Disaster Resilience Grant funding.

[4] NSF FY 2016 budget supported all NEHRP-related activities, excluding Agency Operations and Award Management (AOAM). Budget included support for the NSF portion of the GSN and the earthquake engineering portion of the Natural Hazards Engineering Research Infrastructure (NHERI), but excluded *Earthscope* activities.

[5] USGS FY 2016 budget supported NEHRP-related activities including the USGS Earthquake Hazards Program (EHP) and the USGS portion of GSN ($6.5M).

2.2 NEHRP FY 2017 Budget Requests by Strategic Goal

Table 2.3 lists the FY 2017 NEHRP planning budgets for each agency by strategic goal. These figures are based on agency submissions included in the President's FY 2017 budget request to Congress.

TABLE 2.3 – *NEHRP AGENCY BUDGET REQUESTS for FY 2017*

Strategic Goal	FY 2017 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	0.4	50.7	12.2	**63.4**
Goal B: Develop cost-effective measures to reduce earthquake impacts on individuals, the built environment, and society at large.	4.6	5.1		2.5	**12.2**
Goal C: Improve the earthquake resilience of communities nationwide.	3.8	0.4		16.3	**20.5**
Develop, operate, and maintain NEHRP facilities:					
ANSS				31.2	**31.2**
GSN			3.5	7.3	**10.8**
Total:	**8.5**	**5.9**	**54.2**	**69.5**	**138.1**

Notes on Table 2.3:

[1] Budgets are rounded to the nearest $0.1 million (M). FEMA, NIST, and NSF budgets are those agencies' planned allocations for NEHRP activities from total requested agency appropriations. USGS budget was amount requested for USGS NEHRP activities.

[2] FEMA requested FY 2017 budget supported all NEHRP-related activities, including employee salaries and expenses (S&E).

[3] NIST requested FY 2017 budget supported all NEHRP-related activities, including NEHRP Secretariat (Lead Agency) and NIST Earthquake Risk Reduction in Buildings and Infrastructure R&D Program activities. NIST NEHRP budget included $2.0M of new Disaster Resilience Grant funding.

[4] NSF requested FY 2017 budget supported all NEHRP-related activities, excluding AOAM. Budget included support for the NSF portion of the GSN and the earthquake engineering portion of the NHERI, but excluded *Earthscope* activities.

[5] USGS requested FY 2017 budget supported all NEHRP-related activities including the USGS EHP and the USGS portion of GSN ($7.3M).

Section 3
Statutory Program Highlights

This section summarizes major activity highlights and accomplishments of NEHRP during FY 2015. The organization of this chapter follows that of the NEHRP strategic plan (http://nehrp.gov/pdf/strategic_plan_2008.pdf). 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 Public Law 108–360, Section 103(2). By following the structure of the strategic plan, this report allows the reader to directly assess how accomplishments are furthering progress toward the program's stated goals and objectives. Accomplishments are not categorized by NEHRP agency but, rather, are cast in terms of collective progress toward NEHRP goals.

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 directly supports the congressionally defined NEHRP program activity, "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 decisions sciences" 42 U.S.C. § 7704(a)(2)(C). Strategic Goal A activities include advancing understanding of earthquake phenomena and generation processes, earthquake effects on the built environment, and the social, behavioral, and economic factors linked to implementing risk reduction and mitigation strategies in both the public and private sectors. Strategic Goal A also covers efforts to improve post-earthquake information acquisition and management.

In FY 2015, the NEHRP agencies supported work to improve the fundamental understanding of earthquakes and their impacts. Representative accomplishments and activities under this goal are presented below.

Turning Disaster into Knowledge: Learning from the April 25, 2015 Nepal Earthquake

The NSF-sponsored GEER Association organizes and supports reconnaissance efforts by geotechnical researchers and develops techniques to capture perishable data to learn from these events. In May and June of 2015, a team put together by the GEER Association visited Nepal to evaluate the geotechnical damage and effects spurred by the recent earthquake sequence. Landslides, ground failures, damage to hydropower projects, roadways, bridges, and buildings were

among the features observed. In the Kathmandu Basin, structural damage distributions and recorded ground motion data indicate significant ground motion directivity that, combined with deep basin effects, resulted in significant amplification of ground shaking. Although modern buildings constructed within the basin generally performed well, local occurrences of heavy damage and collapse of reinforced concrete structures were observed.

Presentations from a reconnaissance briefing on observations from the Nepal Earthquake cohosted by GEER, the Pacific Earthquake Engineering Research Center (PEER), and the Earthquake Engineering Research Institute (EERI) are publicly available: http://peer.berkeley.edu/events/2015/07/peer-eeri-geer-gorkha-nepal-earthquake-briefing-july-17-2015/.

A report of the team's findings, complete with photos and preliminary analyses, is available on the GEER Association website: http://www.geerassociation.org/component/geer_reports/?view=geerreports&id=26.

A USGS EDAT, supported by the United States Agency for International Development Office of Foreign Disaster Assistance (USAID OFDA), sent four people from the Earthquake Hazards Program (EHP) and one person from the Landslide Hazards Program (LHP) to Nepal to provide general technical assistance and information, as well as to collect perishable data to understand the earthquake and its impacts. Additional USGS activities in response to the Nepal earthquake sequence are described in Section 5 of this report.

Designing Resilient and Sustainable Buildings

As demonstrated by earthquake events in 2015, high performance buildings, designed for resilience to multiple hazards, such as earthquakes, hurricanes, and floods, are critical to our welfare, livelihood, security, and safety. However, building design decisions are complex as they are made in the context of changing economic, social, technological, and natural conditions. The goal of the NSF Decision Frameworks for Multi-Hazard Resilient and Sustainable Buildings solicitation is to advance knowledge for multi-hazard resilient and sustainable building systems using decision frameworks for selection among alternative building system designs. NSF awarded grants for four new research projects to multidisciplinary teams across eight universities.

One of these awards, a collaboration between researchers at Northeastern and Tufts Universities, emphasizes the importance of taking an interdisciplinary approach to developing a decision framework for designing buildings that are both resilient and sustainable in the face of multiple hazards. The research team is leveraging their expertise in areas such as performance-based engineering, collapse analysis, sustainable architecture design, building lifecycle assessment, economics, and public policy. Their intended framework will go beyond building codes and standards, to support informed decisions based on measuring the environmental impacts of buildings throughout their life, quantifying buildings' functional performance in the face of environmental hazards, and ensuring consistent resilience across multiple hazards.

Extending the Potential for Tall Timber Buildings

Current U.S. building codes prohibit wood construction above five or six stories, partially due to concerns about fire and structural safety. A team of researchers supported by NSF may help change that by demonstrating the potential for a low-damage seismic force resisting system for tall timber buildings. The new system uses cross-laminated timber walls, which are currently being used in regions with no seismic hazard, in buildings up to 13 stories. Timber construction has been shown to have significantly smaller environmental impacts relative to steel and concrete structures. However, before timber construction of tall buildings can be implemented in areas with seismic activity, like the west coast of the U.S., evidence is needed that timber buildings can perform well in all conditions, including earthquakes.

In April 2015, the research team held a public viewing of a component-level test of its wall system. The testing protocol consisted of a sixteen by four foot cross-laminated timber shear wall put under a seismic simulation as a machine applied pressure to push and pull the top of the panel. The outcome was a success, demonstrating that the panel would maintain its structural integrity during the simulated earthquake. The research team will now take lessons learned from component testing and develop design principles for the full building-level. If successful, the projects' findings will advance the use of sustainable building construction techniques in the U.S., reducing the environmental impacts of building construction and increasing the use of U.S. timber, thus supporting rural economies.

Studies of Seismicity Induced by Wastewater Injection

Development of earthquake-resilient buildings and building codes is supported by ongoing studies to better understand earthquake risk in the U.S. The USGS continued to monitor earthquakes in Oklahoma, Kansas, Texas, and Colorado that are believed to be caused by wastewater injection. The additional funding for induced seismicity research, appropriated to USGS by Congress in 2014 and 2015, was used to develop methods to forecast which types of injections in which geologic settings would be likely to induce or trigger earthquakes; to perform comprehensive studies at carefully selected field sites; and, to establish procedures to adapt USGS National Seismic Hazard Maps to account for potential hazards from earthquakes induced in association with the production of oil and gas. Of note, USGS research showed that since 2001 most of the seismicity in the Raton Basin, which straddles the Colorado and New Mexico border, has been induced by wastewater injection, including a damaging M5.3 earthquake. Satellite radar data (InSAR) was used to image the ground displacement caused by that large earthquake, introducing a new method to estimate the depth and sense of slip of faults disturbed by deep fluid injection.

USGS released a new report that describes for the first time how injection-induced earthquakes can be incorporated into U.S. seismic hazard models (https://pubs.er.usgs.gov/publication/ofr20161035). These specialized models will aim to calculate how often earthquakes are expected to occur in the

next year and the likely levels of resulting ground shaking. This report looked at the central and eastern U.S.; future research will incorporate data from the western states as well.[4]

Operational Aftershock Forecasting

For many years, the USGS has been generating automated aftershock forecasts for earthquakes in California. These forecasts are based on statistical analyses of many aftershock sequences recorded over decades of observations. Recently, the USGS has been developing analytical tools and analyzing global seismicity data, working toward an automated capability for forecasting the expected size and frequency of aftershocks that occur after large earthquakes anywhere in the world. Such forecasts could be of value to a wide variety of users, including local officials, emergency responders, and engineers in planning response and recovery efforts, and to inform numerous other risk-mitigating activities following damaging earthquakes.

In 2015, the USGS developed methods and procedures for issuing aftershock forecasts on-demand following large earthquakes anywhere in the U.S. or abroad. The USGS also hosted a workshop attended by several types of potential users of earthquake forecast information, to guide the development of forecast approaches and products to best meet user needs. Results from the workshop, including potential uses of forecast information by a variety of public and private user groups, are summarized in a paper published in Seismological Research Letters (http://srl.geoscienceworld.org/content/87/2A/313.short). Following the April 25, 2015 M7.8 Gorkha earthquake in Nepal, USGS scientists responded to a request from the Department of State to issue aftershock advisories based on these new methods. These advisories were communicated to U.S. Embassy staff and to the public through local media sources.

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 directly supports the congressionally defined NEHRP program activity, "Develop effective measures for earthquake hazards reduction." 42 U.S.C. § 7704(a)(2)(A). Goal B includes activities by the NEHRP agencies to assess earthquake hazards for research and practical application, and to develop tools for advanced loss estimation and risk assessment, improved seismic performance of buildings and other structures, and improved seismic performance of critical infrastructure. Selected accomplishments of the NEHRP agencies that relate to developing resources to assess and reduce risk are presented below.

[4] Note: A one-year national hazard model for injection-induced earthquakes in the central and eastern US was issued by USGS in 2016 and an updated model for injection-induced earthquakes in the CEUS was issued in 2017. See https://earthquake.usgs.gov/hazards/induced/index.php#2017

National Seismic Hazard Assessment Update

In 2015, USGS experts worked with the building design community to adopt new seismic hazard estimates into engineering design maps and building codes. The 2014 update to the USGS National Seismic Hazard Maps provided improved estimates of the likelihood of ground shaking during the lifespan of buildings, bridges, and other structures; work during FY 2015 focused on further improvements. The USGS collaborated with FEMA and the Building Seismic Safety Council (BSSC) to publish design maps for the conterminous U.S., Guam, American Samoa, and the Northern Mariana Islands in the 2015 *NEHRP Recommended Provisions*. Engineering groups are now working to incorporate these maps into the 2016 construction engineering standards of the American Council on Seismic Engineering and the 2018 International Building Code (IBC). The USGS co-hosted a User-Needs Workshop with the ATC that brought together USGS developers of the National Seismic Hazard Maps and a diverse subset of the data user community to provide feedback on the latest (2014) model and associated products and tools. The USGS also released a highly-requested Risk-Targeted Ground Motion Calculator that engineers can use to design buildings with appropriate levels of seismic strengthening.

Also in 2015, the USGS released a report titled, *Earthquake Shaking Hazard Estimates and Exposure Changes in the Conterminous United States* (https://pubs.er.usgs.gov/publication/70155520), which demonstrates that many more U.S. residents may be at risk from damaging earthquakes than previously estimated. The study, published in the journal *Spectra*, looked at changes in both the characterization of the earthquake hazard and the total population since 1996. More than 143 million Americans living in the 48 conterminous States are exposed to potentially damaging ground shaking from earthquakes. When the people living in the earthquake-prone areas of Alaska, Hawaii, and U.S. territories are added, this number rises to nearly half of all Americans. The new exposure estimate is nearly double the previous 2006 estimate of 75 million Americans in 39 states; that doubling is due to significant growth of populations in areas prone to earthquakes, and to improved scientific methods that have refined and expanded the identification of such areas.

Software Tools for Rapid Calculation of Structural Performance and Damage

With more Americans living in earthquake-prone areas, it is important to develop tools for advanced loss estimation and risk assessment. In 2015, NSF supported an award for SBIR to the Haselton Baker Risk Group LLC, of Chico, CA focused on providing software tools for rapid calculation of structural performance and damage during an earthquake and estimation of repair costs for high-performance building design.

Assessment of Performance-Based Seismic Design Methods

PBSD has emerged as an effective means of designing structures to resist earthquake ground motions while allowing structural engineers more latitude in their design approaches, providing building performance in earthquakes to meet specific needs. PBSD permits added design flexibility, but at the expense of significantly more complex engineering analysis, to demonstrate structural

performance. One approach that is being employed is to use the standard used to evaluate existing buildings as the means to test the design of new buildings. The robust analysis and performance requirements found in standards such as the American Society of Civil Engineers (ASCE)/Structural Engineering Institute (SEI) 41-06 *Seismic Rehabilitation of Existing Buildings* establish building performance utilizing complex linear and nonlinear assessment procedures. This compares with the more traditional prescriptive approaches found in building codes such as the IBC. The question is, how do buildings designed using PBSD approaches perform in comparison with those designed using traditional prescriptive building codes? Stated another way, if a building was designed using a prescriptive building code and evaluated using an assessment procedure, the building would pass the assessment if the code and assessment were based on the same performance targets.

NIST concluded a large five-year study of first generation PBSD approaches to determine how well buildings designed using PBSD would perform in comparison with buildings designed using prescriptive methods. The concept was to conduct an evaluation using the ASCE/SEI 41-06 to evaluate buildings designed using the prescriptive rules found in ASCE/SEI 7 *Minimum Design Loads for Buildings and Other Structures*, and codified in the IBC. If the performance rules were consistent between the PBSD approach represented in ASCE/SEI 41 and the prescriptive approach found in ASCE/SEI 7, then all buildings assessed would pass. To test this hypothesis, three different structural steel building systems were studied, including special moment frames, special concentrically braced frames, and eccentric braced frames. Buildings of four, eight, and sixteen stories were evaluated using the four different procedures allowed under ASCE/SEI 41.

The results indicate that there are inconsistencies and that many elements in these buildings failed the ASCE/SEI 41 evaluation, indicating that the performance under ASCE/SEI 7 is not consistent with that assumed with ASCE/SEI 41. NIST research structural engineers are engaged with the ASCE/SEI 41 Standards Committee to identify needed changes to the standard to address issues raised in this work. Moreover, NIST is engaged in similar studies of steel buildings utilizing buckling restrained braces and reinforced concrete moment frame buildings.

The reports on this work are contained in NIST Technical Note (TN) 1863 (February 2015), which consists of three volumes:
Volume 1: Special Moment Frames (http://dx.doi.org/10.6028/NIST.TN.1863-1)
Volume 2: Special Concentrically Braced Frames (http://dx.doi.org/10.6028/NIST.TN.1863-2)
Volume 3: Eccentrically Braced Frames (http://dx.doi.org/10.6028/NIST.TN.1863-3)

Structural Design Technical Briefs

With support from NIST, the ATC produced NIST Grant/Contractor Report (GCR) 15-917-34, *NEHRP Seismic Design Technical Brief 11, Seismic Design of Steel Buckling-Restrained Braced Frames: A Guide for Practicing Engineers* (http://ws680.nist.gov/publication/get_pdf.cfm?pub_id=919849). The techbrief volumes are part of a continuing series of topical, succinct discussions of solutions to practical problems faced by engineering practitioners. As implied in the title for each techbrief,

these volumes provide state-of-the-art guidance to practicing engineers that combines clarification on requirements in building codes and standards, techniques employed by leading practitioners, and recent research results. The volumes are used as references by practicing engineers and in graduate engineering classes in universities. Visit http://www.nehrp.gov/library/techbriefs.htm for a complete list of the NIST/NEHRP Technical Briefs.

NEHRP Recommended Seismic Provisions for New Buildings and Other Structures

FEMA completed the 2015 edition of the *NEHRP Recommended Provisions* (https://www.fema.gov/media-library/assets/documents/107646), a new knowledge-based code resource document intended to translate state-of-the-art research results for engineering design practice. It includes technical code changes developed by the Provisions Update Committee (PUC) and approved through a consensus process at the BSSC of National Institute of Building Sciences. The document incorporated extensive results and findings from recent research projects, problem-focused studies, and post-earthquake investigation reports conducted or supported by various professional organizations, research institutes, universities, material industries, and the four NEHRP agencies.

The 2015 *NEHRP Recommended Provisions* are presented in two Volumes - Volume I, FEMA P-1050-1 and Volume II, FEMA P-1050-2. Volume I is comprised of two Parts - Part I includes recommended new changes and modifications to the adopted ASCE/SEI 7-10 Standard: *Minimum Design Loads for Buildings and Other Structures*, and Part II provides full commentary for Part I, consisting of new commentary integrated with the ASCE/SEI 7-10 commentary. Volume II includes Part III of the *NEHRP Recommended Provisions* which contains resource papers covering new concepts and methods for trial use, and other supporting materials for design professionals.

Since October 2010, FEMA, in collaboration with USGS and NIST, worked with BSSC, its PUC, and 11 issue teams and study groups to help address issues with the current seismic design provisions in the national standards and codes. Over 80 national subject matter experts devoted a tremendous amount of volunteer time into the development process. Their efforts produced the valuable and widely-recognized new *NEHRP Recommended Provisions*, and made a significant impact on the next edition of the national standards and codes.

Technical Guidelines for Seismic Design of Rigid Wall-Flexible Diaphragm Buildings

To further guide development of resilient building practices, a new technical guideline document, FEMA P-1026 *Seismic Design of Rigid Wall-Flexible Diaphragm Buildings: An Alternate Procedure* (https://www.fema.gov/media-library/assets/documents/105764), was published by FEMA in FY 2015. This guideline provides a new design procedure that applies recent research and testing results to improve the seismic performance of "big box" buildings. Large, single-story buildings with rigid walls and flexible diaphragms (often referred to as "big box" or RWFD buildings) are commonly used as warehouse buildings and retail stores in the U.S. In past earthquakes, some

RWFD buildings performed poorly with major collapses. These buildings have stiff external walls constructed of reinforced concrete or masonry, or braced frames of structural steel, and relatively flexible roofs made of metal deck or wood structural panels. The seismic response of this structural type is dominated by large displacements of relatively flexible diaphragms. The new alternative design procedure considers the characteristics of flexible diaphragms for the overall building performance. The study also demonstrates that simple design procedures can be directed at a single building type for better performance. The design procedure has been adopted in Part III of the above-referenced 2015 *NEHRP Recommended Provisions* for trial use by RWFD building designers.

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 directly supports the congressionally defined NEHRP program activity, "Promote the adoption of earthquake hazards 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." 42 U.S.C. § 7704(a)(2)(B).

Goal C includes numerous NEHRP-wide activities to improve the accuracy, timeliness, and content of earthquake information products; to develop comprehensive earthquake risk scenarios and risk assessments; to support development of improved seismic standards and building codes, and advocate their adoption and enforcement; to promote the implementation of earthquake-resilient measures in professional practice and in private and public policies; to increase public awareness of earthquake hazards and risks; and to develop the nation's human resource base in earthquake safety fields. Some representative accomplishments are described below.

Building the Future Professional Base

Building the professional base is key for maintaining the earthquake community's ability to conduct and apply earthquake research. Four NSF awards (1996, 2003, 2009, and 2014) have supported partnering senior researchers with promising young faculty working in the areas of hazards, disasters, and risk research. Senior researchers mentor junior faculty and provide technical training and professional development to build their research skills and foster a broad understanding of emerging issues in disaster research. The current project, *Enabling the Next Generation of Hazards and Disaster Researchers*, has drawn researchers from other fields to disaster research, enhancing the community's depth and enabling multidisciplinary collaborations to promote innovation. The program has supported potentially transformative research on topics such as homeland security, enhanced emergency response, emergency medical services, protecting power and other lifelines, community resilience, and frameworks to reduce losses and speed recovery in vulnerable areas.

NSF also supported Research Experiences for Undergraduates (REU) site programs and supplements to existing awards focused on earthquake issues.

Applied Earthquake Research Grants

Approximately one-quarter of the total USGS NEHRP funding was directed toward earthquake-related research grants and cooperative agreements with universities, State agencies, and private technical firms for research and monitoring. This external funding was leveraged with funds from other federal agencies, states, and the private sector. In FY 2015, USGS supported external activities including: mapping seismic hazards in urban areas; developing credible earthquake planning scenarios including loss estimates; defining the prehistoric record of large earthquakes; investigating the origins of earthquakes; improving methods for predicting earthquake effects; operating ANSS regional seismic networks, and improving the prototype system for an EEW system. The NSF and USGS also funded cooperative agreements with the Southern California Earthquake Center (SCEC), a 40-institution earthquake research consortium.

Public Earthquake Safety Exercises

Engaging with the public to increase public awareness of earthquake hazards and risks is a key component of applying research. In 2015, the USGS partnered with FEMA to provide earthquake scenarios and seismic hazard and risk information to several cities in the Dallas-Fort Worth metropolitan area, a previously quiet area which has experienced five notable swarms[5] of earthquakes since 2008, some of which have been identified as likely induced by wastewater injection. Dallas and other cities are incorporating this information into emergency response procedures and improved public messaging about earthquake safety. Also in 2015, a scenario for an earthquake in southern California served as the basis for the Federal Capstone disaster response exercise and for California's annual Golden Guardian statewide response exercise.

To advance preparedness in California, USGS Scientist Lucy Jones served on a detail as the science advisor for seismic safety to Los Angeles Mayor Eric Garcetti. Jones brought together city officials and leaders in academia, industry, and business to address the earthquake risk and develop an action plan based on her analysis of earthquake hazards and vulnerabilities. The work led to the city's *Resilience by Design* report, which will be translated into regulations that make residents of the city safer.

ShakeOut Earthquake Preparedness Drill

For a broader reach than individual earthquake safety exercises, NEHRP agencies again supported ShakeOut, the world's largest earthquake preparedness drill for governments, schools, businesses, other organizations, and homes. In FY 2015, more than 26 million people participated in

[5] According to Richter (1958), an earthquake swarm is "… a long series of large and small shocks with no outstanding principal event."

ShakeOut activities, including participants from 47 States and U.S. Territories, and 27 Regions worldwide. For the first time, New Mexico participated in ShakeOut, along with Quebec and the Yukon Territory, and Colorado, Montana and Wyoming had separate sites (all had previously participated as part of the Rocky Mountain ShakeOut). In addition, Kansas was added to the Central U.S. ShakeOut and Florida joined the Southeast ShakeOut. NEHRP provides financial support to SCEC to provide personalized State/Territory and regional ShakeOut websites, templates, drill guides, registration support, and technical planning assistance. All ShakeOut exercises benefit from the direct involvement of staff from the NEHRP agencies.

Advancing the Earthquake Early Warning System

EEW is the capability to quickly and automatically identify and characterize an earthquake after it begins; calculate the intensity of ground shaking that is expected to result; and deliver warnings to people and systems that may experience damaging shaking in seconds or minutes. Recent federal, state, and private investments have resulted in a prototype EEW system called ShakeAlert, which has been sending live alerts to selected test users since January of 2012. Reliable public alerts will require more ground-motion sensor stations and additional development to maximize its speed, reliability, and accuracy.

In January 2012, the USGS and its partners began testing a limited-capability, demonstration EEW system that built upon prior USGS investments in the ANSS. A 2014 technical implementation plan describes the technical requirements to build and operate a reliable, public EEW system for the west coast of the U.S.

Because earthquake shaking travels more slowly than electronic signals, it is possible to broadcast warnings to communities after an earthquake has occurred, but before strong shaking arrives. EEW is aimed to warn residents and operational entities of imminent strong ground shaking immediately after a large earthquake has occurred. The warning time, measured in seconds, is proportional to distance from the hypocenter.

The demonstration EEW system in California now has more than 75 test users receiving alerts and has successfully sent test alerts for several damaging earthquakes, including the M5.1 La Habra and the M6.0 South Napa events. One user, the San Francisco Bay Area Rapid Transit District (BART), utilizes the system to slow and stop trains automatically if test alerts of damaging ground shaking are received.

In 2015, Congress enacted an increase of $5.0 million to the USGS "to transition the earthquake early warning demonstration project into an operational capability on the west coast." These funds were used to further the ShakeAlert development effort, including the expansion of seismic network coverage that is needed to ensure accurate earthquake alerts and the integration of real-time GPS data. To support partner activities in EEW, in 2015, approximately $4.0 million was provided through cooperative agreements with the California Institute of Technology, University of California, Berkeley, University of Washington, and University of Oregon to support transitioning

the ShakeAlert EEW system toward a production stage. USGS additionally spent $1 million to purchase new sensor equipment.

3.4 NEHRP Statutory Activity: Program Leadership

There are several statutory NEHRP program management, coordination, and oversight functions. 42 U.S.C. §§ 7704(a)(3) & (5). In FY 2015, the Advisory Committee on Earthquake Hazards Reduction (ACEHR)[6] met three times, including two teleconferences. The Interagency Coordinating Committee[7] did not meet in FY 2015. The working-level Program Coordination Working Group (PCWG), established by the NEHRP Secretariat, met face-to-face six times and held two teleconferences.

NEHRP Secretariat Operations

The NIST NEHRP Secretariat continued to provide program coordination. The office organized and conducted the ACEHR and PCWG meetings and maintained the NEHRP website. This website (http://www.nehrp.gov/) provides information on NEHRP management efforts and products, as well as 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.

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

Public Law 108–360 requires that NEHRP "develop, operate, and maintain" certain facilities essential to the NEHRP mission. 42 U.S.C. § 7704(a)(2)(D). These facilities are the ANSS, maintained and operated by USGS; the GSN, maintained and operated cooperatively by USGS and NSF; and the NHERI, maintained and operated by NSF. Below are reports on the FY 2015 activities and status of these facilities.

Advanced National Seismic System

The ANSS is an effort led by the USGS to support, coordinate, and modernize earthquake monitoring nationwide. The system includes a national backbone seismic network, the National Earthquake Information Center (NEIC), 11 partner-operated regional networks, and the National

[6] ACEHR is composed of 11 to 17 nationally recognized, leading earthquake professionals who are not federal employees and who are appointed to 3-year staggered terms of service. The Chair of the USGS Scientific Earthquake Studies Advisory Committee (SESAC) serves as an *ex-officio* member of ACEHR.

[7] The Interagency Coordinating Committee 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.

Strong Motion Project for monitoring earthquake shaking in the free field and in structures. Thanks to substantial improvements to station coverage and methods for rapid analysis, the ANSS now typically reports on domestic earthquakes within minutes of their occurrence.

In FY 2015, the ANSS station count declined to 2,922 due to a consolidation of operations. The station count includes instruments in 156 structures. As part of the ANSS, the USGS and cooperating universities operate regional seismic networks in areas of higher seismic risk. Regional data is used to monitor active faults and ground shaking, in much greater detail and accuracy than is possible with the national-scale network. Each region has appropriate local data processing capabilities. ANSS regional networks also serve as State or local distribution points for information about earthquakes to the public, local and State agencies, and other regional interests. To support partner activities in earthquake monitoring in 2015, approximately $6.6 million was provided through cooperative agreements for regional seismic and geodetic networks, and structural and geotechnical arrays.

Global Seismographic Network

The GSN consists of 150 stations worldwide. It is jointly supported by the USGS and the NSF, and is operated by the USGS in partnership with the Incorporated Research Institutions for Seismology (IRIS). The GSN provides high-quality seismic data to support earthquake alerts, tsunami warnings, hazard assessments, national security (through detecting underground nuclear tests), earthquake loss reduction, and research on earthquake sources and the structure and dynamics of the Earth.

In 2015, the USGS and IRIS continued to operate the GSN at a high level of data recovery, real-time telemetry performance, and high cost efficiency. The USGS continued to lead a multi-agency effort to develop and procure new borehole sensors, as part of ongoing efforts to maintain and improve the GSN. The GSN data quality has been high in recent years, due to the upgrades of data loggers and the development of software to automatically assess GSN data quality, and to identify and diagnose performance issues. The USGS developed and implemented new software to automatically assess the quality of GSN data, allowing staff at the USGS Albuquerque Seismological Laboratory to identify, diagnose, and fix station performance problems quickly. This has resulted in unprecedented data quality and availability for the USGS-operated stations of the network.

Natural Hazards Engineering Research Infrastructure, the successor to the George E. Brown, Jr. Network for Earthquake Engineering Simulation

The NHERI is the next generation of NSF support for a multi-user, natural hazards engineering research facility, replacing the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES). NEES was a distributed, multi-user, national research infrastructure for earthquake engineering research. NHERI includes both earthquake engineering research infrastructure and wind engineering research infrastructure.

NHERI is a distributed, multi-user, national facility to provide the natural hazards engineering community with access to research infrastructure (earthquake and wind engineering experimental facilities, cyberinfrastructure, computational modeling and simulation tools, and research data), coupled with education and community outreach activities. NHERI will enable the community to make research and educational advances collaboratively that can contribute knowledge and innovation to prevent natural hazards from becoming societal disasters. This knowledge base could potentially transform how future civil infrastructure will be designed and how existing civil infrastructure might be rehabilitated. Civil infrastructure designed to be multi-hazard resilient will contribute toward broader societal goals, i.e., protect people and property, maintain continuity in essential operations and services, and recover rapidly from a natural hazard event.

The following awards were made in FY 2015 for NHERI:

- Cyberinfrastructure, at the University of Texas at Austin;
- Twelve-Fan Wall of Wind at Florida International University;
- Large-Scale, Multi-Directional, Hybrid Simulation Testing Capabilities at Lehigh University;
- Large Wave Flume and Directional Wave Basin at Oregon State University;
- Geotechnical Centrifuges at the University of California, Davis;
- Large, High-Performance Outdoor Shake Table at the University of California, San Diego;
- Boundary Layer Wind Tunnel, Wind Load and Dynamic Flow Simulators, and Pressure Loading Actuators at the University of Florida;
- Large, Mobile Dynamic Shakers for Field Testing at the University of Texas at Austin.

The NHERI cyberinfrastructure award hosts online research and education tools for the natural hazards community (http://www.DesignSafe-ci.org). Tools include the Data Depot for archiving experimental data generated at the NHERI experimental facilities, computational modeling and simulation tools, and a post-disaster, Rapid Response Research (RAPID) Reconnaissance Integration Portal for archiving perishable geotechnical, structural, coastal, and social science data obtained during field work by researchers following an earthquake or windstorm event in the U.S. or abroad.

Along with direct operations and maintenance support for NHERI awardees, NSF will provide separate support for research to be conducted at the NHERI experimental facilities through ongoing research and education programs. The support for such activities primarily will be provided through the existing Engineering for Natural Hazards (ENH) research program in the Civil, Mechanical and Manufacturing Innovation (CMMI) division in the Directorate for Engineering (ENG). The ENH program supports basic research in multi-hazard engineering involving experimental and computational simulations at the NHERI facilities, addressing important challenges in multi-hazard mitigation for constructed civil infrastructure.

Under program solicitation NSF 15-598, NSF competed in FY 2016 the remaining three awards for NHERI: Network Coordination Office, Computational Modeling and Simulation Center, and RAPID facility.

Section 4

FEMA Activities to Promote Implementation of Research Results and Hazard Mitigation Efforts

4.1 Improving the National Design Standard and Building Codes with New Research Results

FEMA collaborated with the national design standard and building code organizations to promote implementation of new knowledge and research results for improving seismic design practices, national design standards, and model building codes. On February 11, 2015, FEMA NEHRP and BSSC held a national workshop to present the new data, analytical study and research results in fourteen special seismic engineering design fields that supported and backed the major code improvements adopted in the 2015 *NEHRP Recommended Provisions*. Over 100 national subject matter experts, representatives of construction material industries, and national code and standard organizations participated in the workshop. Subsequently, all major code-related updates in part 1 of the *NEHRP Recommended Provisions* were submitted to the ASCE consensus committee for developing ASCE 7-16 standard. FEMA and USGS worked with the Code Resource Support Committee (CRSC) at BSSC to develop the updated seismic design value maps proposed for ASCE 7-16, the 2018 IBC, and IRC. As a way to provide feedback from practice to research, FEMA worked with the PUC to identify issues and research needs in seismic design and code regulation for new buildings and other structures. The research needs report covers wide areas of seismic engineering including design and analysis, concepts for revision of analysis requirements, geotechnical and ground motion issues, concrete, masonry, steel, and wood structures, nonbuilding structures, and nonstructural components. This report was completed on Aug 31, 2015 and published on the NEHRP official website for distribution to relevant researchers, institutes, NEHRP agencies, and the general public.

4.2 The Earthquake State Assistance Program

An objective of Public Law 108–360, the Earthquake Hazards Reduction Program Reauthorization Act of 2004, is to improve the understanding of earthquakes and their effects on communities, buildings, structures, and lifelines. To achieve this objective, FEMA has implemented an earthquake hazards reduction assistance program for State and local governments in seismic risk areas. Using Cooperative Agreements as funding instruments, the assistance program provides funding for specific allowable activities that are requested by individual States and Territories, and if approved, implemented by regional earthquake Consortia and national earthquake Partners through the Earthquake Consortium and State Support (ECSS) grant program. Total funding for all FY 2015 Cooperative Agreements was $3,407,050. The following is a sampling of State and Territory activities funded by the ECSS grant program in FY 2015.

Alabama

Alabama had one 2015 NEHRP project consisting of printing 250 large desk calendars for agency partners with Earthquake and 2016 ShakeOut Drill details for outreach and education. The calendars are to assist with the Alabama Emergency Management Agency goal of increasing the participation in the 2016 ShakeOut Drill from state agencies. The calendars are useful in keeping all recipients mindful throughout the year of the earthquake threat and the upcoming 2016 ShakeOut Drill on October 20. As a result of Alabama's work, the ShakeOut participation in Alabama increased significantly in 2016, compared to 2015.

Arkansas

With the help of the Central U.S. Earthquake Consortium (CUSEC), Arkansas provided 200 water heater bracing systems free to citizens of Arkansas.

Billboards were created for ShakeOut awareness across the high-impact areas of Arkansas. As a supplement, brochures were printed to promote ShakeOut and the creation of disaster supply kits.

California

Among the projects that the State of California promotes through NEHRP State Support funding, some of the greatest leverage comes from annual support to California's Earthquake Country Alliance (ECA). ECA is a public-private-grassroots partnership of leading earthquake professionals, emergency managers, government officials, business and community leaders, and others. ECA was founded in 2003 in Southern California and expanded statewide in 2009. In addition to being the locus through which California promotes the annual Great California ShakeOut earthquake drill (10.5 million registered drill participants in 2015), ECA is best known for year-around networking across sectors to expand the base of earthquake education stakeholders, and for developing multi-sector educational resources for California that are widely adapted across the country.

In 2015, California partnered with ECA, SCEC at University of Southern California, and FEMA's contractor, Outreach Process Partners, to create an educational poster to show earthquake self-protective actions in a variety of circumstances. California and ECA continue to coordinate with FEMA's QuakeSmart Business Mitigation Program on a multi-year effort to integrate existing business continuity resources into QuakeSmart's mitigation portal.

ECA activities have cascading impact because they foster participation among earthquake education stakeholders across sectors and regions. Representatives of ECA regional Alliances in Southern California, the Bay Area, and the Redwood Coast serve on a statewide steering committee, and chair their local coordinating committees. Each year, ECA SoCal and ECA Bay Area organize three to four quarterly workshops in various locations in their regions, featuring presentations by local partners and state/federal agencies, sharing from ECA Associates, demonstrations, planning for regional activities, and presentation trainings. Also, ECA organizes speakers, workshops, booths, or information tables at many conferences and events each year to recruit participation in

ECA, ShakeOut, Tsunami Preparedness Week; distribute earthquake and tsunami educational materials; and answer questions about earthquake science, mitigation, and preparedness.

California continues to provide leadership for the annual ShakeOut drill and campaign, which is a singularly successful national public preparedness event. The state could not achieve this leadership role without the "distributed model" of support, networking and collaboration represented by ECA, and without the partnership and support from FEMA Building Sciences' NEHRP team.

Indiana

As in other years, the Indiana Department of Homeland Security and the Indiana Geological Survey partnered together to support the Quake Cottage Earthquake Awareness Program. The program promotes earthquake preparedness education in Indiana. The Quake Cottage is an earthquake simulator that mimics the shaking experienced during earthquakes having magnitudes ranging from 3.0 to 8.0. The 25 x 8 x 14-foot unit mounted on a double-axle trailer features an interior that replicates a typical living room – with items fastened down to protect occupants – and demonstrates the effectiveness of preparatory measures to protect lives and prevent damage to personal property. A large window allows audiences to view participants while the simulator is in operation.

Each Quake Cottage event is designed as an educational experience and is not intended for entertainment purposes. The goal is to provide education about the science of earthquakes and the steps to take to prepare for an earthquake. The priority is to reach a variety of target audiences, including emergency responders, medical professionals, business owners, students and teachers, and the public. The Quake Cottage is available for events from March through November, depending on weather conditions and staff availability.

Kentucky

In FY 2015, 429,919 participants in Kentucky registered for the Great Central U.S. ShakeOut. With earthquake state assistance funds, Kentucky updated its Earthquake Program website, the Facebook Earthquake Program Page, and issued a Governor's Earthquake Awareness Week Proclamation and press release.

Maine

With support from the Northeast States Emergency Consortium (NESEC), the Maine State Assistance Project consisted of incorporating Rapid Observation of Vulnerability and Estimation of Risk (ROVER) and other data on critical and essential facilities into Hazards U.S. (HAZUS). This project identified and analyzed more than 4,280 facilities for earthquake and other hazard vulnerabilities and risk.

Mississippi

CUSEC and the Mississippi Emergency Management Agency (MEMA) co-hosted a three-day workshop of local, state, and Federal emergency managers, non-profit organizations, and the private sector to address earthquake hazards, mitigation, and response and recovery planning considerations. Approximately 100 people participated in the event, which included most counties that would be affected by a New Madrid Seismic Zone earthquake.

With support from CUSEC, MEMA participated in the 2015 National Earthquake Program Managers (NEPM) Meeting in Charleston, South Carolina. At the meeting were state and territorial earthquake program managers, senior leadership from State and Federal Government, the NEHRP Secretariat, as well as the NEHRP earthquake consortia and program partners. Portions of the meeting were dedicated to strategic planning for increasing emergency management's involvement within NEHRP, through the NEPM working group and the National Emergency Management Association (NEMA) Earthquake Subcommittee.

MEMA co-hosted a statewide preparedness workshop and training for emergency management professionals with CUSEC and the Mississippi Civil Defense and Emergency Management Association. MEMA, the American Institute of Architects, and CUSEC provided an earthquake-themed breakout to local emergency managers on the New Madrid Seismic Zone and post-disaster safety assessment programs that would benefit Mississippi following an earthquake or other disaster. Approximately 300 people participated in the workshop.

MEMA and CUSEC worked with neighboring states to improve regional post-disaster safety assessment/building inspector programs.

Missouri

In August and September 2015, planning began to participate in an October 2015 regional Building Inspector training program in Missouri, hosted by the Missouri Structural Assessment and Visual Evaluation (SAVE) Coalition and Missouri State Emergency Management Agency. This FEMA-154 Rapid Visual Screening training prepares volunteers to inspect schools for earthquake vulnerabilities. The team of inspectors assess all school structures, then follow up with a confidential report on vulnerabilities. Federal funds covered both the training class and expenses for visits to three school districts. Approximately 40 people participated in the training in March, with several teams visiting schools later in the year.

The Missouri SAVE Coalition Regional Exercise, held at Jefferson Barracks National Guard Post in St. Louis, involved more than 200 people from ten states. Inspectors deployed in a simulation of a M7.6 earthquake in the New Madrid Seismic Zone, inspecting barrack buildings with simulated earthquake damage. The team practiced GPS and a new Geographic Information System (GIS) based data collection system developed by CUSEC. The system allows inspectors to perform safety assessments on their smart phones or tablet devices and provides real-time situational awareness of field data. The exercise tested deployment procedures, Emergency Management Assistance Compact (EMAC) mutual aid, communication, command and control, exercise development, and working with other groups.

Missouri SAVE Coalition On-site Leader Training prepares current SAVE members for leadership in the field during deployments. Training included overview of call-down procedures, use of GPS, logging inspections, and other operational functions of post-disaster building inspections. Approximately 40 people participated.

Along with CUSEC and the Federal Alliance for Safe Homes (FLASH), Missouri participated in the QuakeSmart Business Summit at St. Louis University. Presentations were related to earthquake preparedness and resiliency for businesses, and approximately 100 people participated.

Montana

In the Montana Scenario Project, the USGS, working with the Montana Bureau of Mines and Geology, completed 17 custom ShakeMap scenarios for the State of Montana representing maximum credible scenarios for different faults across the state. A full suite of HAZUS earthquake loss estimations was developed for each of the 17 scenarios**.** The risk assessments are then worked into a suite of outreach materials by EERI for public risk communication and dissemination to various partners in the State of Montana.

North Carolina

North Carolina Emergency Management (NCEM) publicized and participated in the Great ShakeOut. Department and Division Public Information Officers (PIOs) worked to distribute information on the event. School district PIOs were sent a customizable press release, a graphic, and fliers from the SouthEast ShakeOut (SESO) national campaign. NCEM sent a customizable press release, proclamation, social media messages, four graphics, and four fliers (two in English, two in Spanish) from the SESO national campaign to County EM coordinators. In addition, NCEM sent a short paragraph about the ShakeOut to the Department of Public Instruction for inclusion in its electronic newsletter to principals and superintendents. The release went to Department of Public Safety media lists across the state.

Using funding provided through the State Assistance program, NCEM also assisted with regional hazard mitigation plan updates – many of which identify earthquake as a hazard.

Oklahoma
In 2015, Oklahoma hosted multi-day FEMA earthquake training in April and July and printed 20,000 Earthquake Guide brochures for distribution to the most affected parts of the State.

With support from CUSEC, Oklahoma had 57,265 participants in ShakeOut, up almost 16,000 from 2014. Additionally, State Assistance funding was requested and approved for the printing of 20,000 Earthquake Guide brochures for distribution to the most affected parts of the State.

Oregon
Oregon continued to support preparedness and outreach efforts to local communities. Oregon participates in the yearly ShakeOut exercise, with more than 550,000 Oregonians participating in the 2015 annual ShakeOut drill, a 41 percent increase from 2014.

The Cascadia Region Earthquake Workgroup (CREW), in association with the Oregon Office of Emergency Management (OEM), developed geographic information system (GIS) information on seismic vulnerability during a Cascadia Subduction Zone earthquake and tsunami to identify populations that will be isolated due to infrastructure damage. This GIS information will be integrated in the system known as RAPTOR, the coordination tool used by the Oregon OEM.

Visitors to the Oregon coast may not be aware of the tsunami hazard. This population is particularly vulnerable to disasters because they are separated from their normal support systems. The Oregon Coast Visitor Earthquake & Tsunami Awareness project enables hospitality providers to inform their guests about the tsunami hazard in a positive way. Oregon has also partnered with CREW to create *Hospitality begins with Safety*, an online awareness training for employees on how to prepare for earthquakes. This is part of a larger outreach effort for the Oregon Coastal region. Another outreach effort is the Oregon Road Show project, initially started under the 2009 State Assistance grant; 1,700 people were educated at the 2015 event.

Puerto Rico
In partnership with the Puerto Rico Emergency Management Agency (PREMA) and Puerto Rico Seismic Network Program (PRSN), Puerto Rico completed a Spanish language translation of the QuakeSmart Community Resilience Program for businesses and organizations.

South Carolina
South Carolina was approved for NEHRP funds for three projects, the first being funds to travel to meetings which would have otherwise been missed opportunities. Other funds were used for printing copies of the earthquake guide which has existed for several years—the only update was a social media icon on the back. Finally, to promote the building inspection program, Earthquake Awareness had ShakeOut magnets made and the Public Information Coordinator handled dissemination.

Tennessee

The Tennessee Emergency Management Agency (TEMA) developed the Tennessee Structural Assessment & Visual Evaluation (TNSAVE) Coalition, Inc. with eight engineer and architect professional associations. One purpose of TNSAVE was to organize and implement a volunteer pre- and post-disaster building inspection program which would deploy to multi-hazard disaster sites and integrate into the FEMA National Incident Management System (NIMS)/Incident Command System (ICS) local response operations to support local government damage analysis. Planning, training, and exercises have been conducted across the state in preparation for team deployment operations. Members include the American Council of Engineering Companies/Tennessee, Associated General Contractors of Tennessee, American Institute of Architects/Tennessee, American Society of Civil Engineers - Tennessee Section, Geotechnical Institute of the ASCE of Tennessee, Society of American Military Engineers - Nashville Post, Structural Engineers Association of Tennessee, and the Tennessee Society of Professional Engineers.

TEMA partnered with CUSEC to support the "Ride the Fault" bicycle tour event which had 500 riders from both continental and international clubs participate. Thousands of citizens in Tennessee, Missouri, Arkansas, Kentucky, and Illinois joined in the outreach awareness festivities surrounding the week-long, 200-mile bike tour, which followed the New Madrid Earthquake Fault Zones. Tennessee provided volunteers to host the riders at rest stops throughout the tour.

TEMA conducted school planning sessions partnering with the TN Department of Education to make earthquake awareness and preparedness a point-of-emphasis in 10 county school districts in the West Tennessee New Madrid Fault Zone primary threat areas.

The Tennessee Army and Air National Guard partnered with TEMA to conduct statewide, full-scale exercise maneuvers which involved units and armories in 50 communities with over 5,000 military and civilian participants. Operational activities included search and rescue, hazardous materials response, security, transportation assurance, points-of-distribution exercises, and movement of air-frame for logistic support – C-17's from 164th Air Guard at Memphis International hub and HH-60 Blackhawks for troop movement and medical evacuation. The scenario involved responding to damages from a major earthquake event along the New Madrid Fault Zone and in support areas.

Vermont

In partnership with the Vermont Geological Survey, Vermont Homeland Security and Emergency Management, University of Vermont, Norwich University, and NESEC, Vermont conducted a meeting and training session in Burlington to train essential and critical facility managers on seismic risk and mitigation. The meeting had more than 25 attendees and raised public awareness of earthquake risk in northern Vermont.

Washington

Beginning in 2012, the state of Washington joined in the Great ShakeOut Earthquake drill. Washington State made strategic investments and established partnerships with media providers to actively encourage registration and participation in the inaugural Great Washington ShakeOut. Washington continues to build on its efforts through a statewide media campaign that will promote earthquake safety, ShakeOut registration, and participation in the drill, and encourage preparedness and mitigation within homes, schools, businesses, and hospitals. A total of 1,083,263 people participated in the Great Washington ShakeOut Drill in 2015, a decrease from 1,090,892 in 2014.

Washington identified common issues across multiple state resilience plans that could be jointly resolved through regional strategies to address a Cascadia Subduction Zone earthquake. For example, critical infrastructure and lifeline impacts may cross state borders and have a regional economic impact if disrupted.

The Low English Proficiency (LEP) Program was created within Washington State Military Department Emergency Management Division. The LEP Program Coordinator has been hired to improve communications to vulnerable populations throughout the State of Washington to include translation of public education and outreach materials, attend and interpret during various public workshops and forums, and serve in the role of a Liaison Officer during activations of the State Emergency Operations Center.

Washington State led the Nation in Tsunami Vertical Evacuation Structures, also known as Project Safe Haven. The first of these tsunami safe areas will be Ocosta Elementary School located in Westport. This grassroots initiative in the Westport community has greatly influenced neighboring coastal communities. The community of Long Beach designed a tsunami safe berm as the first tsunami safe shelter (https://www.mil.wa.gov/blog/news/post/nations-first-tsunami-vertical-evacuation-center-breaks-ground) on the Long Beach Peninsula, located next to the Long Beach Elementary School. It is estimated to hold a capacity of 850 people. In addition, the Quinault Indian Nation plans to build a 500-car parking garage that also can serve as the first tsunami evacuation shelter on the North Beach.

Activities for the ASCE 31-Tier 1 and HAZUS evaluation of 15 schools within Thurston County are supported by EERI resources, in collaboration with local expertise, such as the Structural Engineering Association of Washington, to complete earthquake safety inspections and identify appropriate mitigation measures.

Section 5
NEHRP Response to Major Earthquakes in FY 2015

Globally, there were 14,588 earthquakes of M4.0 or greater in 2015. This worldwide activity was consistent with prior year averages of approximately 40 earthquakes per day of M4.0, or approximately 14,500 annually. There were 19 earthquakes worldwide of M7.0 or higher. These earthquakes caused 9,612 deaths, a significant increase compared to 664 earthquake-related deaths in 2014. Most of these fatalities – 8,964, as reported by the United Nations Office for Coordination of Humanitarian Affairs – are attributed to the M7.8 earthquake that occurred on April 25 in Nepal. It was followed by an M7.3 aftershock on May 12 that killed an additional 218 people in Nepal. Deadly earthquakes also occurred in Afghanistan and Chile. The largest earthquake that occurred in the U.S. during 2015 was a M6.9 event that occurred near Umnak Island, Alaska, on July 27. Due to its remote location, this event caused no damage or casualties.

In the central U.S., seismicity continued to increase in 2015, with 32 earthquakes of M4.0 and greater in Kansas, Oklahoma, and Texas, compared to 17 in 2014, and the USGS recorded over a thousand earthquakes above M3.0 in this region. Although none of these events caused significant damage, they generated shaking felt by the residents, raising concern. Most, if not all, of these events were induced by the injection disposal into underground rock formations of wastewater used in or produced by oil and gas recovery operations. Studies by the USGS and others have found the majority of such earthquakes to have resulted from the injection into underground rock formations of wastewater resulting from petroleum extraction processes. This wastewater consists of saltwater produced along with the oil and gas, and with fluids use in hydraulic fracturing.

The USGS worked in cooperation with the Oklahoma Geological Survey, the Kansas Geological Survey, and Southern Methodist University in the deployment of temporary seismic equipment to record and study these earthquakes.

Afghanistan

On October 26, an M7.5 earthquake occurred in the Hindu Kush region of northeastern Afghanistan near the border with Pakistan. Because the earthquake occurred at a depth of 210 kilometers, the ground shaking at the surface was attenuated. Nevertheless, this earthquake caused widespread destruction in Afghanistan and Pakistan. In Pakistan alone, the event resulted in the deaths of 232 people and injured another 1,500. Unreinforced structures made of stone, adobe, or brick masonry performed very poorly in this earthquake. In many cases these structures suffered total collapse, accounting for most of the casualties. In Pakistan, reinforced concrete structures, designed and built-in compliance with the national building code, performed well during the earthquake with no major damage reported.

Nepal

On April 25, an M7.8 earthquake occurred in Nepal about 75 kilometers northwest of Kathmandu. At least 8,964 people were killed and 17,000 injured by this earthquake and its aftershocks. An estimated 500,000 structures were destroyed and another 269,000 damaged. Included in the casualties were 180 people killed from the collapse of Nepal's historic Dharahara Tower, and 20 people killed and 120 injured from an avalanche at the Mount Everest Base Camp. Many landslides were triggered by the earthquakes, causing damage to roads and power lines throughout central Nepal. Damage estimates exceeded $5 billion in Nepal. Additional damages and casualties were reported in India, China, and Bangladesh. Damage was most severe to unreinforced masonry buildings, although non-engineered, reinforced concrete framed buildings also suffered substantial damage and failures. Wood frame structures, although rare in Nepal, performed relatively well.

The severe consequences of this earthquake triggered broad international response and recovery efforts to provide immediate aid and interim food, shelter, and other necessities. A wide range of post-earthquake activities and investigations were carried out by the NEHRP agencies. USGS activities included interagency and external coordination; the NEIC's rapid "situational awareness" products for the mainshock; aftershock monitoring, including two large aftershocks of M6.7 and M7.3, and the posting of a public aftershock advisory product in coordination with the U.S. Embassy in Nepal; the National Strong Motion Project's release of strong ground motion records from a NetQuakes station in Kathmandu; work to initiate a request for satellite imagery acquisition and, subsequently, images from U.S., international, and commercial satellites were acquired and analyzed to provide images used for scientific studies and for search and rescue; and conducting numerous media interviews to provide public information about the earthquake. USAID's OFDA supported a USGS EDAT which, as part of its Phase-I project, sent four people from the EHP and one person from the LHP to Nepal to provide general technical assistance and information, as well as to collect perishable data to understand the earthquake and its impacts.

Also from the U.S., reconnaissance teams from the EERI, the GEER Association, and the USGS went to Nepal to study the impacts of the earthquake and to assess the extent and causes of damages. The EERI and the GEER reports are available at: http://www.eqclearinghouse.org/2015-04-25-nepal/2016/05/18/eeri-reconnaissance-team-report-on-the-nepal-earthquake-is-now-available/ and http://www.geerassociation.org/administrator/components/com_geer_reports/geerfiles/Nepal_GEER_Report_V1_15.pdf, respectively.

Chile

On September 16, an M8.3 earthquake struck 10 kilometers offshore of central Chile, 48 kilometers west of Illapel, and 200 kilometers north-northwest of Santiago. This was a major earthquake, causing a tsunami warning to be issued for the Pacific Ocean basin. Despite the size of the earthquake and its aftershocks, losses were not severe and were limited to the immediate coastal region. Thirteen people were killed, and 2,280 houses were destroyed, with another 2,400 heavily

damaged and uninhabitable. Slope failures along coastal roads caused closures, but no major disruptions in traffic flow. There was considerable non-structural damage to homes, businesses, and hospitals.

There was significant tsunami damage in the coastal towns of Coquimbo and Tongoy, where ocean wave heights reached 4.5 meters and run-up distances were over 500 meters. No significant tsunami damage was reported outside of the immediate coastal area. It was estimated that approximately one million people responded to tsunami warnings and safely evacuated the immediate coastal area.

Five years earlier, in 2010, an M8.8 earthquake struck near the Chilean region of Maule, 200 kilometers south of Santiago. This event and the tsunami it generated killed 521 people, destroyed or severely damaged 200,000 dwellings, and caused an estimated $30 billion in damages. The lower losses in the 2015 earthquake are attributed to the actions taken to avoid the losses suffered in 2010.

Conclusion

The impacts of earthquakes in Afghanistan, Nepal, and Chile demonstrate important lessons relevant to NEHRP goals and objectives. A comparison of the impacts of these earthquakes demonstrates that earthquake preparedness and long-term mitigation measures, such as implementing building design and construction practices based on earthquake resistant standards or codes, are the key to avoiding human and material losses in earthquakes.

Section 6
Related Activities Supporting NEHRP Goals

Public Law 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. 42 U.S.C. § 7704(a)(4)(E). Highlights of these programs and activities are described below.

6.1 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 the USGS and the National Aeronautics and Space Administration. The EarthScope Facility was composed of three core components: the Plate Boundary Observatory (PBO), constructed and operated by the University NAVSTAR Consortium (UNAVCO); the San Andreas Fault Observatory at Depth (SAFOD), constructed by Stanford University in cooperation with USGS, and operated from 2008-2013 by UNAVCO; and the United States Seismic Array (USArray), constructed and operated by IRIS.

In FY 2013, NSF completed the first of two stages in a plan to integrate elements of the EarthScope Facility with other seismic and geodetic facilities operated by IRIS and UNAVCO. The Geodesy Advancing Geosciences and EarthScope (GAGE) Facility unites PBO and the core geodetic facilities that UNAVCO historically operated and managed, while the Seismological Facilities for the Advancement of Geosciences and EarthScope (SAGE) unite USArray and the core seismic facilities IRIS has historically operated and managed. SAGE includes the GSN, a long-standing component of NEHRP jointly supported by NSF and USGS. NSF plans to issue a solicitation in FY 2016[8] for proposals for a National Geophysical Observatory for Geoscience (NGEO), which would provide facility capabilities to succeed SAGE and GAGE at the end of the current awards in September 2018.

The EarthScope Facility has left a legacy of data, operational stations, and physical samples that are all being used for NEHRP-related research and operational activities today. For example, the Central and Eastern United States Seismic Network (CEUSN) project, which began in FY 2013 with funding from NSF and USGS, has converted 158 USArray Transportable Array stations to long-term operations and upgraded the instrumentation and data collection to support critical infrastructure monitoring and other needs. These stations will be jointly supported through FY

[8] NSF issued the solicitation in February 2016, with a deadline for proposals in December 2016. NSF is currently reviewing proposals received pursuant to that solicitation.

2017, at which point their long-term operation is unfunded. These stations greatly increase the density of long-term, continuously recording seismic stations in the region.

EarthScope seismic and geodetic stations in the western U.S. are being incorporated into nascent EEW systems under development by USGS and its regional network partners. For example, 15 USArray stations have been adopted by the State of Oregon for inclusion in its EEW system, while 12 additional stations in California and Washington are being considered for future adoption. Furthermore, USGS is supporting efforts to incorporate into EEW systems the real-time Global Navigation Satellite System (GNSS) data from geodetic stations originally installed as part of PBO, and now operated as part of GAGE.

NSF continues to oversee SAFOD via the EarthScope program, in collaboration with USGS. Since 2009, the USGS has been operating a seismometer immediately above repeating earthquakes at a depth of 3 km, probing the inner workings of the processes that initiate earthquakes on this major plate boundary fault. Through an award to Texas A&M University, NSF supports archiving and distribution of physical samples of the deep fault materials obtained in 2007; researchers around the world are analyzing these samples to understand a variety of physical properties related to fault deformation and earthquake generation.

6.2 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.

6.3 International Activities

U.S.-China Cooperation in Earthquake Studies

Highlights from cooperative research on earthquake hazards reduction with China include the exchange of strong ground motion data for several damaging earthquakes, with magnitudes ranging from 6.4 and 7.0 that occurred in China. A bilateral workshop on earthquake research was held in

California in September 2015, prior to the SCEC Annual Meeting, and was attended by a dozen scientists from each country. Three Chinese visiting scholars spent a year at the USGS in Menlo Park, California. In addition, several delegations from the China Earthquake Administration visited the U.S. to review and discuss earthquake research and hazard reduction policies. Seismic data continued to flow to the USGS from the ten-station China-U.S. cooperative broadband seismic network that is operating in China. Earthquake probability estimates, the application of Light Detection and Ranging (LiDAR), and EEW were topics of mutual interest. Several joint publications on earthquake research were completed. A delegation from China visited the USGS in Menlo Park, California, and the University of California at Berkeley to learn more about U.S. progress on EEW.

U.S.-Japan Cooperation on NEES/E-Defense Collaborative Earthquake Engineering Research Program

Through NSF support, a U.S.-Japan planning meeting for the continuing NEES/E-Defense Collaborative Earthquake Engineering Research Program was held on September 15-16, 2015, at the E-Defense Earthquake Simulator Facility, Hyogo Earthquake Engineering Research Center in Miki, Japan. The meeting participants reviewed and discussed the results of recent and current NEES/E-Defense research projects and developed a roadmap for high priority research opportunities that could be enabled by the NHERI and E-Defense facilities. Among the topics discussed were continuing a five-year collaborative research program, collaborating on a social science approach for disaster mitigation, and broadening research interests to include water-related disasters. In FY 2015, NSF provided an international travel award to the University of California at Berkeley to support U.S.-Japan research collaboration on the seismic design and testing of two full-scale, ten-story reinforced concrete buildings at the E-Defense facility in Japan. A first meeting was held on September 13-14, 2015, in Miki, Japan. By working with Japanese researchers, the U.S. researchers will contribute to the design and testing of the structures, and will gain access to the test data to use in subsequent research analyses. The data will serve the U.S. national need of improving the resilience of buildings and communities against future earthquakes.

16th World Conference on Earthquake Engineering

Abstracts for the 16th World Conference on Earthquake Engineering were due by September 15, 2015, and the conference took place on January 9-13, 2017, in Santiago, Chile(http://www.iitk.ac.in/nicee/wcee16/). The world conference takes place every four years and is designed to promote collaboration and sharing of scientific research on seismic engineering. Beginning in FY 2015, a FEMA staff member served as an invited member of the Conference Organizing Committee for the conference.

See Section 5 above for specific NEHRP (USGS and NSF) international earthquake reconnaissance efforts during the year.

Appendix A

List of Acronyms and Abbreviations

ACEHR	Advisory Committee on Earthquake Hazards Reduction
ANSS	Advanced National Seismic System
AOAM	Agency Operations and Award Management
ASCE	American Society of Civil Engineers
ATC	Applied Technology Council
BART	Bay Area Rapid Transit District
BSSC	Building Seismic Safety Council
CEUSN	Central and Eastern United States Seismic Network
CMMI	Civil, Mechanical and Manufacturing Innovation
CREW	Cascadia Region Workgroup
CRSC	Code Resource Support Committee
CUSEC	Central United States Earthquake Consortium
ECA	Earthquake Country Alliance
EDAT	(USGS) Earthquake Disaster Assistance Team
EERI	Earthquake Engineering Research Institute
EEW	earthquake early warning
EHP	Earthquake Hazards Program
EMAC	Emergency Management Assistance Compact
ENG	Directorate for Engineering
ENH	Engineering for Natural Hazards
FEMA	Federal Emergency Management Agency
FLASH	Federal Alliance for Safe Homes
FY	fiscal year
GAGE	Geodesy Advancing Geosciences and EarthScope
GCR	(NIST) Grant/Contractor Report
GEER	Geotechnical Extreme Events Reconnaissance
GIS	geographic information system
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSN	Global Seismographic Network
HAZUS	Hazards U.S.
IBC	International Building Code
InSAR	Satellite radar data
IRIS	Incorporated Research Institutions for Seismology
LEP	Low English Proficiency
LHP	Landslide Hazards Program
LiDAR	Light Detection and Ranging

M	magnitude
$M	(dollars) million
MEMA	Mississippi Emergency Management Agency
MitFLG	Mitigation Framework Leadership Group
NBC	National Building Code
NCEM	North Carolina Emergency Management
NEES	George E. Brown, Jr. Network for Earthquake Engineering Simulation
NEHRP	National Earthquake Hazards Reduction Program
NEIC	(USGS) National Earthquake Information Center
NEMA	National Emergency Management Association
NEPM	National Earthquake Program Managers
NESEC	Northeast States Emergency Consortium
NGEO	National Geophysical Observatory for Geoscience
NHERI	Natural Hazards Engineering Research Infrastructure
NIMS/ICS	(FEMA) National Incident Management System/ Incident Command System
NIST	National Institute of Standards and Technology
NSF	National Science Foundation
OEM	Oregon Office of Emergency Management
OMB	Office of Management and Budget
OSTP	White House Office of Science and Technology Policy
PBO	Plate Boundary Observatory
PBSD	performance-based seismic design
PCWG	(NEHRP) Program Coordination Working Group
PEER	Pacific Earthquake Engineering Research Center
PIO	Public Information Officer
PPD	Presidential Policy Directive
PUC	Provisions Update Committee
R&D	research and development
RAPID	(NSF) Rapids Response Research funding mechanism
REU	Research Experiences for Undergraduates
ROVER	Rapid Observation of Vulnerability and Estimation of Risk
RWFD	Large, single-story buildings with rigid walls and flexible diaphragms
S&E	salaries and expenses
SAFOD	San Andreas Fault Observatory at Depth
SAGE	Seismological Facilities for the Advancement of Geosciences and EarthScope
SAVE	Structural Assessment and Visual Evaluation
SBIR	Small Business Innovation Research
SCEC	Southern California Earthquake Center
SDR	Subcommittee on Disaster Reduction
SEI	Structural Engineering Institute

SESO	SouthEast ShakeOut
TEMA	Tennessee Emergency Management Agency
TN	(NIST) Technical Note
TNSAVE	Tennessee Structural Assessment & Visual Evaluation
UNAVCO	University of NAVSTAR Consortium, nonprofit university-governed consortium that facilitates geosciences research using geodesy
USAID OFDA	United States Agency for International Development's Office of Foreign Disaster Assistance
USArray	United States Seismic Array
USGS	United States Geological Survey