Annual Report of the National Earthquake Hazards Reduction Program

For Fiscal Year 2017

December 2019

FEMA

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

USGS
science for a changing world

This report covers the National Earthquake Hazards Reduction Program (NEHRP or Program) activities during fiscal year (FY) 2017. It is submitted to the Congress by the Interagency Coordinating Committee on Earthquake Hazards Reduction (Interagency Coordinating Committee), 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 National Earthquake Hazards Reduction Program Reauthorization Act of 2004 (Public Law 108-360).

The members of the Interagency Coordinating Committee are as follows:

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Under Secretary of Commerce for Standards and Technology and Director
National Institute of Standards and Technology
U.S. Department of Commerce

Mr. Peter Gaynor
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Federal Emergency Management Agency
U.S. Department of Homeland Security

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Executive Summary

Public Law 108–360 requires the Interagency Coordinating Committee submit an annual report to Congress on NEHRP budgets and activities.[1] Pursuant to the requirement, the Interagency Coordinating Committee is submitting this annual report, through NEHRP agency leadership, covering the FY 2017[2] activities of the four NEHRP agencies[3] and their progress toward reducing the impacts of future earthquakes in the United States (U.S.). This report also summarizes actual NEHRP-related budgets by agency for FY 2018 and Program budgets requested by the Administration for FY 2019.

NEHRP is a broad working partnership of four agencies providing the leadership and technical resources needed to reduce the human, economic, and societal losses caused by earthquakes in the U.S. and its territories. NEHRP meets this challenge by supporting the research and operations needed to study causes and effects of earthquakes, by developing and encouraging the use of building design recommendations to reduce earthquake damage and disruption, and by sponsoring activities that advocate earthquake risk reduction awareness and practices nationwide.

Significant accomplishments by the NEHRP agencies during FY 2017 are given below.

FEMA. In FY 2017, FEMA reintroduced Direct State Assistance as an option for receiving earthquake hazards reduction assistance from FEMA. The Direct State Assistance option allows states and territories that can provide a fifty percent cash match, to apply for and receive grant funding directly from FEMA. After 2011, all FEMA earthquake hazards reduction assistance was provided through non-profit organizations that prioritized and managed the implementation of approved state projects. The reintroduction of the Direct State Assistance funding option not only diversifies FEMA's ability to provide earthquake assistance, it emphasizes the agency's commitment to building a culture of earthquake preparedness and readying the nation for catastrophic earthquakes.

> FEMA continued to bolster nationwide earthquake hazard resilience with up-to-date risk information and new technical guidelines. FEMA continued its development of the Performance-Based Seismic Design (PBSD) Guidelines to accompany the published assessment methodology provided in FEMA P-58, *Seismic Performance Assessment of Buildings* products and conducted two public workshops to obtain review input from stakeholders. FEMA and USGS collaborated in an update of FEMA P-366, *Hazus Estimated Annualized Earthquake Losses for the United States*. This report provides estimated earthquake losses and is

[1] This report is being submitted for FY 2017. In FY 2018, the NEHRP Act (42 U.S.C. 7701 et seq.) was amended. This report references the version of the NEHRP Act that was in effect during the reporting period, FY 2017.

[2] This report covers FY 2017 as defined by the Federal Government, a period that began on October 1, 2016, and ended on September 30, 2017.

[3] 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).

widely used for informed decision-making and planning in various earthquake mitigation activities. FEMA published FEMA P-1000, *School Safety Guide for Natural Hazards,* an operational resource for schools for preparing and responding to earthquakes and other natural hazards.

NIST. During FY 2017, NIST sustained its core NEHRP mission of carrying out research and development to improve through building codes and standards and practices for structures and lifelines. This included advancing building codes and standards, as well as engineering practice, for structures and lifeline infrastructure in an effort to mitigate the risks posed to the built environment and society-at-large from earthquakes. Ongoing and initiated research activities at NIST focused on increasing advancement and implementation of performance-based seismic engineering procedures for new and existing buildings. NIST completed component testing for a multi-year study on the seismic behavior of steel beam-columns, which has advanced the analytical modeling capabilities and assessment of these components in seismic force-resisting steel buildings. Further, NIST continued to investigate the usage of high-strength materials for concrete components and evaluate methods and algorithms to measure the analytical collapse resistance of buildings. Based on the observations of building performance during the 2010 Canterbury and 2011 Christchurch earthquakes in New Zealand as well as the 2010 Chile earthquake, NIST continued its efforts to assess and benchmark U.S. building codes and engineering standards. NIST maintained close working relationships with standards development organizations (SDOs) to advance seismic standards for analysis and design of new buildings and assessment and retrofit of existing buildings.

In addition to its lead agency responsibilities, NIST further supported NEHRP partner agencies by contributing technical expertise for reviews of Federally-funded projects as well as solicited proposals seeking funding. NIST funded and managed several grantees through the Disaster Resilience Research Grants Program.

NSF. During FY 2017, NSF supported research that led to new platforms and networks for interdisciplinary scientists, social scientists, and engineers to develop research frameworks for interdisciplinary disaster research, catalog existing data sets and measures, and coordinate in the event of a natural disaster. The vision is to prepare individual researchers and teams to carry out extreme events rapid reconnaissance research that is coordinated, comprehensive, coherent, ethical, and scientifically rigorous.

NSF supported research on the development and demonstration of techniques that will allow the rapid collection, organization and dissemination of data and images used by earthquake disaster response and investigation teams.

In the Geosciences Directorate, NSF continued to support the Global Seismographic Network (GSN) as well as the Southern California Earthquake Center (SCEC) in cooperation with the USGS. In addition to awards through disciplinary programs GEO/EAR provided support through Rapid Response Research (RAPID) awards to scientists to acquire data on the Pawnee earthquake that occurred in Oklahoma in 2016 with a 5.8 magnitude (M5.8) and the Kaikoura earthquake with a M7.8 in New Zealand.

USGS. During FY 2017, the USGS created a suite of nearly 800 new earthquake shaking scenarios (ShakeMaps) for the continental U.S.. The scenarios are at scales useful to municipalities planning earthquake preparedness measures.

The USGS also continued to monitor and study earthquakes in Oklahoma, Kansas, Texas, and Colorado that are believed to be caused by deep-well injection of wastewaters commonly resulting from the production of oil and natural gas using enhanced recovery techniques. The USGS updated an annual model and forecast of potential ground-shaking hazards from both human-induced and natural earthquakes. The USGS worked with building code committees to adopt USGS seismic hazard information into the 2018 International Building and Residential Codes.

Section 1 – Introduction

The NEHRP is a four-agency program established by Congress "to reduce the risks of life and property from future earthquakes and increase the resilience of communities in the United States."[4] 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. NIST serves as the lead agency. The roles of the NEHRP agencies are well-defined. Although there is no overlap or duplication of effort, there is close coordination and collaboration between agencies. In fact, completion of tasks by one NEHRP agency often depend on the data, assessments, and research generated by another. NEHRP continues to encourage research and data sharing amongst researchers and institutions, and provides the important link to implementation throughout communities with seismic risk in the U.S. and territories of the U.S..

The FY 2017 NEHRP annual report provides an overview of NEHRP agency budgets, a description of the statutory Program activities, State activities, and non-NEHRP related activities that support NEHRP goals. These activities promote resilience preparedness and support furthering the goals established in the NEHRP Strategic Plan in response to the Program effectiveness assessment by the Advisory Committee on Earthquake Hazards Reduction (ACEHR). This report and prior NEHRP annual reports are available at https://www.nehrp.gov/about/reports.htm.

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

The NEHRP agencies have distinct roles and responsibilities that are mutually supportive, as described briefly below.

FEMA is responsible for developing effective earthquake risk reduction tools and promoting their implementation, as well as supporting the development of disaster-resistant building codes and standards.

NIST's mission is to promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life. NIST serves as the lead agency for NEHRP and supports both the Interagency Coordinating Committee that oversees the planning, management, and coordination of the Program and the ACEHR that assesses the Program. In addition to the lead agency responsibilities, NIST carries out research and development to improve through building codes and standards and practices for structures and lifelines. In doing so NIST develops and conducts research activities to evaluate and test earthquake-resistant design and construction practices for implementation into building codes and engineering practice.

[4] 42 U.S.C. § 7702.

NSF supports basic research and research facilities in earth sciences, engineering, and social, behavioral, and economic sciences relevant to the understanding of the causes and impacts of earthquakes and to developing practical measures to reduce their effects. This support is carried out primarily through research grants by the Directorates of Engineering and Geosciences to individual universities, university consortia, and other organizations.

USGS provides the Nation with earthquake monitoring and notification, delivers regional and national seismic hazard assessments, conducts targeted research to improve these functions, and coordinates post-earthquake investigations.

Section 2 – Program Budgets

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[5], defined three major strategic 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 the 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. 42 U.S.C. § 7704(a)(2)(C).
Goal B: Develop cost-effective measures to reduce earthquake impacts on individuals, the built environment, and society at large.	Develop cost-effective measures for earthquake risk reduction. 42 U.S.C. § 7704(a)(2)(A).
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. 42 U.S.C. § 7704(a)(2)(B).
Develop, operate, and maintain NEHRP facilities.	Develop, operate, and maintain the Advanced National Seismic System (ANSS), NHERI[6], and the GSN. 42 U.S.C. § 7704(a)(2)(D).

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

Public Law 108–360 requires the NEHRP annual report include, for each agency participating in the Program and for each Program activity defined in the legislation, the Program budget by agency when the report was developed (i.e., the fiscal year following the period covered in the report) and the requested program budget by agency for the next FY. 42 U.S.C. § 7704(a)(4). Program budgets by agency for the reporting period (FY 2017) are presented in Table 2.2. Program budgets by

[5] Because the NEHRP Strategic Plan was based on funding levels exceeding appropriated levels, the 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.

[6] The Natural Hazards Engineering Research Infrastructure (NHERI) is the successor to the NSF-supported George E. Brown Jr. Network for Earthquake Engineering Simulation (NEES). NHERI is a distributed, multiuser, national facility that provides research infrastructure for the natural hazards research community, including earthquake and wind engineering experimental facilities, cyber infrastructure, computational modeling and simulation tools, and research data.

agency when the report was developed (FY 2018) are presented in Table 2.3, showing the funding that each participating agency is directing to accomplish the goals and objectives specified in the strategic plan. Table 2.4 identifies the NEHRP funding by agency requested or anticipated for FY 2019. Funding for the development, operation, and maintenance of NEHRP facilities supports the ANSS and the GSN.

2.1 NEHRP Enacted FY 2017 and FY 2018 Budgets by Agency and Strategic Goal

Table 2.2 lists the FY 2017 NEHRP budgets, by strategic goal, for the four NEHRP agencies: FEMA, NIST, NSF, and USGS.

Table 2.2 – *NEHRP AGENCY BUDGETS for FY 2017*

Strategic Goal	FY 2017 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	13.5	**64.6**
Goal B: Develop cost-effective measures to reduce earthquake impacts on individuals, the built environment, and society at large.	4.6	4.6		3.4	**12.6**
Goal C: Improve the earthquake resilience of communities nationwide.	3.8	0.3		17.2	**21.3**
Develop, operate, and maintain NEHRP facilities:					
ANSS				30.2	**30.2**
GSN			3.5	6.6	**10.1**
Total:	**8.5**	**5.2**	**54.2**	**70.9**	**138.8**

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 NEHRP activities.

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

[3] NIST FY 2017 budget supported all NEHRP-related activities, including the lead agency NEHRP Office (formally NEHRP Secretariat) and NIST Earthquake Risk Reduction in Buildings and Infrastructure Research and Development (R&D) Program activities. Budget included $1.3M of new Disaster Resilience Research Grants Program funding for earthquake-related scientific research.

[4] NSF FY 2017 budget supported all NEHRP-related activities, excluding Agency Operations and Award Management (AOAM). Budget included support for the NSF portion of the GSN ($3.5M) and the earthquake engineering portion of the NHERI, but excluded EarthScope activities.

[5] USGS FY 2017 budget supported NEHRP-related activities, including the USGS Earthquake Hazards Program (EHP) and the USGS portion of the GSN ($6.6M).

Table 2.3 – *NEHRP AGENCY BUDGETS for FY 2018*

Strategic Goal	FY 2018 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		62.2	13.5	**75.8**
Goal B: Develop cost-effective measures to reduce earthquake impacts on individuals, the built environment, and society at large.	4.6	4.1		3.4	**12.1**
Goal C: Improve the earthquake resilience of communities nationwide.	3.8	0.3		17.2	**21.3**
Lead agency Program support		0.8			**0.8**
Develop, operate, and maintain NEHRP facilities:					
ANSS				49.3	**49.3**
GSN			3.5	6.7	**10.2**
Total:	**8.5**	**5.2**	**65.7**	**90.1**	**169.5**

Notes on Table 2.3:

[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 NEHRP activities.

[2] FEMA FY 2018 budget supported all NEHRP-related activities, including employee S&E.

[3] NIST FY 2018 budget supported all NEHRP-related activities, including the lead agency NEHRP Office and NIST Earthquake Risk Reduction in Buildings and Infrastructure R&D Program activities. Budget included $1.3M of new Disaster Resilience Research Grants Program funding for earthquake-related scientific research.

[4] NSF FY 2018 budget supported all NEHRP-related activities, excluding AOAM. Budget included support for the NSF portion of the GSN ($3.5M) and the earthquake engineering portion of the NHERI, but excluded EarthScope activities.

[5] USGS FY 2018 budget supported all NEHRP-related activities, including the USGS EHP and the USGS portion of the GSN ($6.7M). The amount for ANSS included funding for the development and operation of the ShakeAlert earthquake early warning system. The FY18 appropriation included $16.4M in "one-time" funding and did not include $8.0M supplemental funding for seismic network restoration following hurricane Maria.

2.2 NEHRP FY 2019 Budget Requests by Agency and Strategic Goal

Table 2.3 lists the FY 2019 NEHRP planning budgets for each agency by strategic goal. These figures are based on agency submissions included in the President's FY 2019 budget request to Congress.

TABLE 2.4 – *NEHRP AGENCY BUDGET REQUESTS for FY 2019*

Strategic Goal	FY 2019 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		57.0	13.0	**70.1**
Goal B: Develop cost-effective measures to reduce earthquake impacts on individuals, the built environment, and society at large.	4.6	4.1		3.2	**11.9**
Goal C: Improve the earthquake resilience of communities nationwide.	3.8	0.3		16.6	**20.7**
Lead agency Program support		0.8			**0.8**
Develop, operate, and maintain NEHRP facilities:					
ANSS				18.2	**18.2**
GSN			3.5	4.9	**8.4**
Total:	**8.5**	**5.2**	**60.5**	**55.9**	**130.1**

Notes on Table 2.4:

[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 the amount requested for NEHRP activities.

[2] FEMA requested FY 2019 budget support all NEHRP-related activities, including employee S&E.

[3] NIST requested FY 2019 budget supports all NEHRP-related activities, including the lead agency NEHRP Office and NIST Earthquake Risk Reduction in Buildings and Infrastructure Research and Development Program activities. Budget request included continued $1.3M for Disaster Resilience Research Grants Program funding.

[4] NSF requested FY 2019 budget supports all NEHRP-related activities, excluding AOAM. Budget request included support for the NSF portion of the GSN ($3.5M) and the earthquake engineering portion of the NHERI, but excluded EarthScope activities.

[5] USGS requested FY 2019 budget supports all NEHRP-related activities, including the USGS EHP and the USGS portion of GSN ($5.0M).

Section 3 - NEHRP Activities by Strategic Goal

This section summarizes major activity highlights and accomplishments of the NEHRP during FY 2017. The organization of this chapter follows the NEHRP strategic plan http://nehrp.gov/pdf/strategic_plan_2008.pdf). The strategic plan defines NEHRP activities in terms of broad strategic goals, more specific objectives, and related strategic priorities. The goals are directly linked to NEHRP activities defined in 42 U.S.C. § 7704(a)(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 identified by the NEHRP agency but are cast in terms of collective progress towards the NEHRP goals.

3.1 Goal A: Improve Understanding of Earthquake Processes and Impacts

This strategic goal 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). In FY 2017, 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.

Updating Seismic Design Criteria for Building Codes (FEMA)

The Project 17 Committee formed by FEMA at the Building Seismic Safety Council (BSSC) for developing the next generation seismic design value maps completed its evaluation for acceptable seismic risks, and balancing uncertainty and accuracy for design ground motions. The Project 17 Committee has determined to retain the current rules and formula for generating the next generation of seismic design ground motion values, primarily based on the risk-targeted maximum considered earthquake methodology. The Committee is also developing a multi-period spectral methodology to be applied to the 2018 USGS seismic hazard maps. Additionally, it is collaborating with the NEHRP Provisions Update Committee[7] (PUC) to reform the Seismic Design Category (SDC) designation – a basic procedure of seismic risk classification used for building design. This effort is aimed at reducing potential switching of SDC classifications for regions where small fluctuations in projected seismic hazards have caused code cycle-to-code cycle change of their SDC classifications.

[7] The PUC was formed at the BSSC of the National Institute of Building Sciences and consists of national subject matter experts and FEMA, NIST, and USGS representatives.

Research Coordination Network in Hybrid Simulation for Multi-Hazard Engineering (NSF)

Hybrid simulations are powerful cyber-physical research methodologies that integrate physical experiments with computational simulations to observe and evaluate the performance of engineering systems under realistic natural hazard loading conditions, such as earthquakes. These experiments enable knowledge generation and innovations that reduce fatalities and minimize economic loss resulting from earthquakes and natural hazards. A growing interdisciplinary and international community of researchers are using hybrid simulation to address societal problems related to multi-hazard engineering.

Existing technical barriers have limited advancements in hybrid simulation. NSF-supported researchers at Purdue University are establishing a research coordination network (RCN) to accelerate progress in advanced hybrid simulation methodologies to address societal grand challenges, build capacity in laboratories, and build partnerships among engineering disciplines. This RCN aims to facilitate the scientific advances needed to establish the theory of, and expand the capacity for hybrid simulation as it applies to earthquakes, windstorms and other natural hazards. Digital artifacts produced by the RCN, such as computational models, experimental data, and learning materials, will be shared through the NHERI DesignSafe-CI.org web portal.

Extreme Events Reconnaissance (NSF)

Under an NSF award, University of Colorado, Boulder is developing two new platforms and corresponding networks to help researchers respond to and overcome long standing challenges in the advancement of the hazards and disaster field, including earthquakes. The two platforms, Social Science Extreme Events Reconnaissance and Interdisciplinary Science and Engineering Extreme Events Reconnaissance, will leverage databases and information resources to build capacity of the social sciences, engineering, and interdisciplinary hazards and disaster research communities.

Rapid Response Research Investigating Unanticipated Geotechnical Phenomena from the April 2016 Kumamoto Earthquake Sequence in Japan (NSF)

NSF supported, via its post-disaster RAPID award mechanism, researchers at Brigham Young University and the University of Colorado, Boulder in a collaborative grant with Japan to investigate unanticipated and poorly understood geotechnical phenomena following the April 2016 Kumamoto earthquake sequence. This grant utilizes state-of-the-art remote sensing techniques to collect perishable data on surface topology, soil deformation, and structure settlement from liquefaction and landslide sites. This collection of geotechnical, seismic, geologic and topographical information, combined with historic site information, allows for laboratory tests and simulations to evaluate soil resistance to liquefaction. This grant is advancing the science and practice of geotechnical earthquake engineering by enhancing the fundamental understanding of seismic-induced ground deformations and liquefaction triggering. Further, preliminary field and laboratory data collected from this grant will inspire a larger international collaborative research effort to more thoroughly investigate the observed unique geotechnical phenomena and damage from this series of earthquakes.

Natural Hazards Center (NSF)

NSF continued its support for the Natural Hazards Center (NHC) at the University of Colorado, Boulder. The NHC disseminates hazard-related information through its web portal (https://hazards.colorado.edu/); two newsletters (the bimonthly Natural Hazards Observer and biweekly Disaster Research); co-editing of the American Society of Civil Engineers journal, the *Natural Hazards Review*; organizing and hosting three annual workshops; providing library and information services; support for post-disaster, rapid response research; and communications with the media and the general public concerning disaster risk reduction. During July 9-12, 2017, the NHC held its 42nd Annual Natural Hazards Research and Applications Workshop in Broomfield, CO.

New Earthquake Shaking Scenarios (USGS)

The USGS created a suite of nearly 800 new ShakeMap earthquake scenarios developed for the continental U.S. The scenarios are at scales useful to municipalities planning earthquake preparedness measures. Scenario ShakeMaps quantify the shaking that would result from significant earthquakes, and are widely used for earthquake drills and planning exercises, and by engineers, emergency responders, operators of critical utilities and lifelines, city planners and the financial sector. Users can choose from an extensive range of possible earthquake scenarios distributed throughout at-risk areas of the conterminous U.S. A new mapping interface leverages ArcGIS Server and ArcGIS Online to display locations, ruptures, and maximum shaking intensities. The earthquake scenario work is being done in conjunction with FEMA and other partners to include earthquake loss estimates, and with a wide variety of public (agencies), private (companies/utilities), and research sector stakeholders.

Earthquake Monitoring and Hazard Assessment in the Central United States (USGS)

The USGS continued to monitor and study earthquakes in Oklahoma, Kansas, Texas, and Colorado believed to be caused by deep-well injection of wastewaters commonly resulting from the production of oil and natural gas using enhanced recovery techniques. The USGS updated an annual model and forecast of potential ground-shaking hazards from both human-induced and natural earthquakes. The new hazard model estimated the frequency and the strength of earthquake ground shaking that could occur in the U.S. during calendar year 2017. The model showed that approximately three million people live and work in areas of the central and eastern U.S. (CEUS) with potential for damaging shaking from induced seismicity. This one-year estimate—which complements the existing 50-year National Seismic Hazard Model—forecasts ground motion hazards that can increase or decrease with time depending on commercial and regulatory decisions. The calendar year 2016's forecast has been used by states, federal agencies, and private companies in risk mitigation decisions; for example, the U.S. Army Corp of Engineers used the model to estimate seismic hazard at key facilities and decide where more detailed risk evaluation was warranted.

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

This strategic goal directly supports the congressionally-defined NEHRP activity, "Develop effective measures for earthquake hazards reduction." 42 U.S.C. § 7704(a)(2)(A). 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. Representative agency accomplishments and activities under this goal in FY 2017 are presented below.

Development and revision of earthquake resistant building codes. (FEMA, NIST, and USGS)

The FEMA-supported NEHRP PUC, established to develop the 2020 edition of NEHRP Recommended Seismic Provisions for New Buildings and Other Structures, conducted three meetings in FY 2017. The PUC voted to adopt the American Society of Civil Engineers (ASCE)/Structural Engineering Institute (SEI) 7-16 Minimum Design Loads and Associated Criteria for Buildings and Other Structures as the base document for the new edition of the NEHRP Recommended Seismic Provisions and developed several ballots to approve update proposals. NIST and USGS each provide agency representation on the PUC that serve as subject matter experts and provide a knowledge transfer mechanism between agency-supported research activities and the PUC.

During FY 2017, FEMA continued the project to develop a pre-standard for residential seismic retrofitting. This project is co-funded and co-managed by the California Earthquake Authority and the FEMA Earthquake Hazards Reduction Program. The goal of this project is a consensus standard that could then be adopted into the International Existing Building Code.

Developing Performance-Based Design Guidelines (FEMA)

Current building codes are intended to provide a life-safety level of protection. During a design-level earthquake, a code-designed building could achieve the life safety goal but could still be damaged and be out of service for some period of time, or even be damaged so severely that demolition may be required. PBSD is a concept that permits the design and construction of buildings with a quantitative understanding of the risk of life, occupancy, and economic losses that may occur in future earthquakes, which would allow a building owner or regulator to select the desired performance goal for their building.

The FEMA Earthquake Program continued its Phase 2 Project with the Applied Technology Council (ATC) to develop the PBSD Guidelines. The Guidelines are based on FEMA's Performance Assessment Methodology found in FEMA P-58 products. In May 2017, the project sponsored two workshops in San Francisco, CA. The first workshop targeted building owners and their representatives to get their feedback on several draft stakeholder products. The second workshop presented findings on how the PBSD Guidelines can be used to evaluate the performance of a series of code-complying buildings and how their performance could be improved. The goal was to review and modify several building fragility formulas used in the FEMA P-58 Performance Assessment Calculation Tool (PACT) to assess building performance, making

PACT more accurate and reliable. This led to the release of an updated version, PACT 3.0 in early FY 2017.

Seismic Safety Assessments for Concrete Buildings (FEMA)

In FY 2017, FEMA continued to develop an Assessment Methodology for Existing Concrete Buildings. The result of this work was the Version 6 report, which presents the results of fifteen trial evaluations done to test the draft wall assessment methodology, and was presented in a workshop held in Los Angeles, CA on September 19, 2017. The project is now entering its final year in 2018.

Seismic Design Recommendations Completed for Regions at Moderate Risk (FEMA)

FEMA completed a new technical resource document *Recommended Simplified Provisions for Seismic Design Category B Buildings* (FEMA P-1091) in September 2017. This document offers the local building code officials, design engineers and other professionals a simplified set of design provisions for Seismic Design Category B (SDC B) regions. SDC B is considered moderate seismic risk but must still follow rigorous seismic design procedures and requirements in accordance with the building code. The provisions in FEMA P-1091 are based on Chapter 24 of the 2015 NEHRP Recommended Seismic Provisions and fully compatible with the latest ASCE 7-16 standard. The document will make seismic design and compliance checks simpler and easier to implement in SDC B regions.

Retrofitting for Seismic Safety (FEMA)

FEMA Earthquake Program staff led a joint project meeting on June 7, 2017 of the Project Management Committee and the Project Oversight Committee for the ATC project (ATC-124) to Develop Design Examples for Seismic Retrofitting Using ASCE/SEI 41-13. The development of the various design examples is progressing well and will be ready for review by the Structural Engineers Association of California on schedule.

Guidelines and Tools for Use in Engineering Practice (NIST)

During FY 2017, NIST sustained its core NEHRP mission of carrying out research and development to improve through building codes and standards and practices for structures and lifelines. This included advancing building codes and standards, as well as engineering practice, for structures and lifeline infrastructure in an effort to mitigate the risks posed to the built environment and society-at-large from earthquakes. Ongoing and initiated research activities at NIST focused on increasing advancement and implementation of performance-based seismic engineering procedures for new and existing buildings. NIST published NIST GCR 17-917-45: *Recommended Modeling Parameters and Acceptance Criteria for Nonlinear Analysis in Support of Seismic Evaluation, Retrofit, and Design*. This project was coupled with three other publications:

- NIST GCR 17-917-46, V1: *Guidelines for Nonlinear Structural Analysis for Design of Buildings Part I – General*
- NIST GCR 17-917-46, V2: *Guidelines for Nonlinear Structural Analysis for Design of Buildings Part IIa – Steel Moment Frames*

- NIST GCR 17-917-46, V3: *Guidelines for Nonlinear Structural Analysis for Design of Buildings Part IIb – Concrete Moment Frames*

This project supports the development of new or updated modeling characteristics for structural components used in the analytical model of a structure to evaluate forces and deformations to compare with a desired performance in PBSD.

Nearly every earthquake investigation reveals damages to nonstructural components (e.g., HVAC equipment, ceiling tile assemblies, facade), driving repairs costs and downtime. To align with research efforts focused on structural components, NIST published NIST GCR 17-917-44: *Seismic Analysis, Design and Installation of Nonstructural Components and Systems – Background and Recommendations for Future Work*. This document will help spearhead research activities focused on the performance of nonstructural components during an earthquake.

Component testing for a multi-year study on the seismic behavior of deep, slender wide-flange steel beam-columns was completed in FY 2017. Results from this work advanced the analytical modeling capabilities and assessment of these components in seismic force-resisting steel systems. A project report summarizing the project will be published in FY 2020.

Based on the observations of building performance during the 2010 Canterbury and 2011 Christchurch earthquakes in New Zealand as well as the 2010 Chile earthquake, NIST continued its project to assess and benchmark U.S. building codes and engineering standards. Further, NIST continued to investigate the usage of high-strength materials for concrete components and evaluating methods and algorithms to measure the analytical collapse resistance of buildings.

In FY 2017, NIST initiated a project investigating the seismic performance of wind-load governed steel buildings located in the central and eastern U.S. The goal of this project was to improve the resilience of these buildings by identifying the seismic risks and then determine if there can be a reduction in the life-cycle construction cost by developing more efficient seismic resistance.

NIST funded and managed several grantees through the Disaster Resilience Research Grants Program, see Appendix A.3, and completed a study on estimating the costs of a seismic retrofit (NIST TN 1973: *A Methodology for Estimating Seismic Retrofit Costs*).

Revised Annualized Earthquake Loss Estimate for the U. S. (USGS and FEMA)

In FY 2017, the USGS and FEMA collaborated to complete and publish a new annualized earthquake loss (AEL) estimate for the U.S. The national AEL is $6.2 billion per year, 38% higher than FEMA's 2008 estimate. This comprehensive study highlights that earthquakes continue to pose significant threat to humans and the built environment throughout the U.S. and that severe impacts from high earthquake hazard and concentrated exposure are not limited to California. The new estimate used the 2014 USGS National Seismic Hazard Model, updated census-based population data, and revised economic exposure estimates of the national building stock. Among other uses, FEMA will use the new results, presented at the state, county, metropolitan, and city levels, for future state grant programs for earthquake hazard mitigation.

Applying Seismic Hazard Assessments in Building Codes (USGS)

The USGS worked with building code committees to adopt USGS seismic hazard information into the 2018 International Building and Residential Codes. This was done via the 2015 NEHRP Recommended Seismic Provisions and the 2016 ASCE 7 Standard for Minimum Design Loads, both of which incorporated the 2014 USGS National Seismic Hazard Model. The USGS also began incorporating new updates into the National Seismic Hazard Model in preparation for a major draft release in 2018; this work included collaboration with the Pacific Earthquake Engineering Research Center (PEER) on a major update to the calculation of seismic ground motions in the central and eastern U.S.

New Earthquake Faulting Forecast for California (USGS)

The Uniform California Earthquake Rupture Forecast (UCERF), version 3, was completed and published in FY 2017 and is the first forecast model to provide self-consistent earthquake rupture probabilities over intervals from more than a century to less than an hour. The USGS led the development of a series of UCERF models, each providing estimates of earthquake locations, magnitudes and rates of occurrence underpinning seismic hazard assessments, including the USGS National Seismic Hazard Model.

Earthquake Early Warning, ShakeAlert, Prototype Completed (USGS)

Version 1.2 of the ShakeAlert Earthquake Early Warning (EEW) system was rolled out in April 2017. This milestone extends the "production prototype" that was rolled out in California in FY 2016 to Washington and Oregon, creating a fully integrated ShakeAlert system for the West Coast. The system does not yet support public warnings, but this version allows selected early adopters to develop pilot implementations demonstrating the system's utility and pave the way for broader use. The USGS, along with partners from state governments, universities, and private foundations have been co-developing the ShakeAlert system for the three West Coast states since 2006. The USGS has a goal of limited public alerts by FY 2018. To reach full public operation the system needs about one thousand more seismic sensors and more geodetic sensors in California, Oregon and Washington, as well as more reliable telecommunications paths. Also, faster methods of public mass notification are needed, and a campaign must be executed to educate the public about EEW alerts and how to respond to them.

3.3 Goal C: Improve the Earthquake Resilience of Communities Nationwide

This strategic goal 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). 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 increasing public safety and reducing losses in future earthquakes. Work under this goal includes the monitoring and reporting of seismic activity worldwide. Representative agency accomplishments and activities under this goal in FY 2017 are presented below.

School Safety Guidelines Completed (FEMA)

The FEMA Earthquake Program completed and published a School Safety Guide for Natural Hazards (FEMA P-1000). This multi-hazard publication provides information on natural hazards to help schools be better prepared and better able to respond, recover, and mitigate future natural hazards. This guide focuses on operational guidance (what to do before, during, and after an event) as well as physical protection (what can be done to the structure and facility to improve safety).

State Assistance Grants for Earthquake Preparedness (FEMA)

FEMA manages the Direct State Assistance Grant Program reducing the risks to life and property from future earthquakes in the United States through the establishment and maintenance of an effective earthquake hazards reduction program. The FY 2017 Direct State Assistance Grant Program provided $616,651.00 to states, territories, and local communities to increase and enhance the effective implementation of earthquake risk reduction. By making this funding available, States and local communities were able to develop seismic mitigation plans; prepare inventories and conduct seismic safety inspections of critical structures and lifelines; update building codes, zoning codes, and ordinances to enhance seismic safety; increase earthquake awareness and education; and encourage the development of multi-state groups that support local earthquake safety and the other eligible program activities. The outcomes of this grant program were significant as it increased knowledge of earthquake hazard, risks, and mitigation actions that can be taken, thus, resulting in a nation more resilient against earthquakes.

Promoting Earthquake Safety and Awareness Nationwide (FEMA)

Nationwide activities included the annual National Earthquake Program Managers (NEPM) Meeting, the annual Great ShakeOut event, and nationwide training provided through the FEMA National Earthquake Technical Assistance Program (NETAP). In FY 2017, 40 in-person trainings with 1,796 participants were hosted in 13 states/territories and two national webinars had a total of 2,000 attendees.

Support Development and Implementation of Codes, Standards, and Engineering Practice (NIST)

During FY 2017, NIST sustained its support to the development of national building codes and engineering standards in an effort to mitigate the risks posed to the built environment and society-at-large from earthquakes. NIST provided technical leadership and expertise to SDOs to advance ASCE 7: *Minimum Design Loads and Associated Criteria for Buildings and Other Structures* and ASCE 41: *Seismic Rehabilitation of Existing Buildings*, while further providing management leadership to the development of new engineering standards, ACI 369: *Guide for Seismic Rehabilitation of Existing Concrete Frame Buildings and Commentary* and AISC 342: *Seismic Provisions for Evaluation and Retrofit of Existing Structural Steel Buildings*, which focus on assessment and retrofit of concrete and steel structural building components, respectively. In addition, NIST promoted implementation of earthquake-resilient measures in professional practice and in private and public policies through dissemination of research findings at invited technical lectures, webinars, presentations and

publications at applicable conferences and committee meetings, and peer-reviewed publications.[8] NIST published its thirteenth technical brief (NIST GCR 17-917-47) on structural design issues titled *Seismic Design of Precast Concrete Diaphragms*. This techbrief provides concise guidance regarding a significant change to diaphragm design provisions in the 2016 edition of ASCE 7. These activities and products advance the state-of-the-art and the state-of-the-practice in earthquake engineering, and are integral to ensure broad-reaching impacts for NIST research activities in support of NEHRP.

Natural Hazards Engineering Research Infrastructure (NSF)

The NSF supported the NHERI Network Coordination Office (NCO) at Purdue University serves as the central hub of NHERI multi-hazards research, coordinating work at the various NHERI experimental facilities, forging national and international partnerships, and organizing education and outreach efforts. The NHERI NCO organized a Research Experiences for Undergraduates (REU) program during the summer of FY 2017 and a Summer Institute for graduate students and early career faculty in July 2017.

Student Support and Training (NSF)

The SCEC that is supported jointly by NSF and USGS, supports internships of students during the summer as well as research of investigators studying different aspects of earthquake hazards in Southern California. Most awards in NSF Geosciences that support the NEHRP program support the training of students and mentoring of postdoctoral fellows to promote training of the future workforce.

Creating Web-based Seismic Design Tools for Engineers (USGS)

The USGS created web-based tools that provide civil and structural engineers with seismic hazard information that supports engineering design. These tools are now heavily used and depended on by engineers, nationwide, for quantitative data on possible earthquake ground motions. The website, developed in coordination with the ASCE, receives hundreds of thousands of hits per year, mostly from engineers who are designing buildings and making policy decisions. In 2017, the USGS centralized these capabilities into a Unified Hazard Tool, providing seismic hazard, selection of custom maps, and access to site-specific design value parameters.

Assessing Los Angeles Water Supply Vulnerabilities (USGS)

USGS scientists are engaged with the City of Los Angeles on building lifeline resilience to earthquakes, including work to identify and mitigate vulnerabilities to the city's critical water supply routes. Of particular concern is the 110-year-old Elizabeth Tunnel, the city's main water aqueduct,

[8] NIST was invited to present results from work focusing on seismic evaluation of existing buildings and accompanying code changes to the Structural Engineering Association of Utah Annual Convention [short course], National Council of Structural Engineers Association (NCSEA) [webinar], and at the 2017 NCSEA Structural Engineering Summit [presentation]. NIST also published several reports, notably a 4-volume set focusing on advancing component models for seismic evaluation of buildings; NIST GCR 17-917-45: *Recommended Modeling Parameters and Acceptance Criteria for Nonlinear Analysis in Support of Seismic Evaluation, Retrofit, and Design*.

which crosses the San Andreas fault 300 feet below the surface. As a result, the Elizabeth Tunnel could be severed by fault slip in a major earthquake. USGS is working with the Los Angeles Department of Water and Power on earth science investigations of the Elizabeth Tunnel. The work includes geodetic monitoring of the tunnel, to enable rapid measurement of fault offset in the event of an earthquake, and geological field and borehole investigations to determine the location and width of the fault zone. The configuration of the fault and the tunnel intersection is being used by engineers to design temporary and long-term retrofit solutions.

Science Plan for Subduction Zone Earthquakes Released (USGS)

The Earth's most powerful earthquakes and tsunamis—along with destructive landslides and volcanic eruptions—occur in subduction zones, where two plates collide, and one is thrust beneath another. The U.S. has multiple subduction zones. These are found in Alaska, Washington, Oregon, and California; the commonwealths of Puerto Rico and the Northern Marianas; and the territories of American Samoa, Guam, and the U.S. Virgin Islands. One or more of these regions will likely experience a catastrophic subduction zone event in the coming decades, as well as smaller, more frequent, but still potentially destructive events. The USGS has released a strategic plan for building the crucial scientific information needed to make our nation more resilient to subduction zone hazards. USGS Circular 1428, Reducing Risk Where Tectonic Plates Collide — A Plan to Advance Subduction Zone Science, is a blueprint for building the crucial scientific foundation needed to inform the policies and practices that can make our Nation more resilient to subduction zone-related hazards. The plan defines USGS science priorities and identifies key partnerships with other organizations involved in related scientific research, emergency management, policy making, and planning.

Instrument Upgrades for the Global Seismic Network (USGS)

In FY 2012, Congress provided $5.7 million to the Department of Energy (DOE)'s National Nuclear Security Agency for the replacement of aging and degraded seismic sensors of the GSN. The DOE transferred most of those funds to the USGS for the development and purchase of new borehole seismic sensors, completed in FY 2017. The new sensors are being installed. The resulting improvements will help ensure that the GSN remains the core worldwide system for earthquake and tsunami monitoring, nuclear treaty monitoring research and Earth science research and education.

Section 4 – Other NEHRP Statutory Activities

4.1 NEHRP Lead Agency Activities (NIST)

NEHRP Office

The NEHRP Office at NIST, which supports NIST's roles and responsibilities as lead agency of NEHRP, continued to provide several statutory program management, coordination, and oversight functions. 42 U.S.C. §§ 7704(b)(1) & (b)(5).

In FY 2017, the Interagency Coordinating Committee did not convene. The ACEHR met face-to-face twice and held two webinars. Additionally, NIST manages the working-level Program Coordination Working Group (PCWG), which is comprised of leaders and managers within the four NEHRP agencies who sit at levels within their respective organizations to facilitate the day-to-day operations of their NEHRP activities, to facilitate interagency communication and coordination. The PCWG met face-to-face once and three times by teleconference.

The NIST NEHRP Office continued to provide program coordination. The office organized and conducted the ACEHR and PCWG meetings and maintained the NEHRP website (http://www.nehrp.gov/). This website 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.

The lead agency Program Office also fulfills all required ACEHR reporting functions for NEHRP including notification of public meetings, documentation of meetings and dissemination of appropriate notifications and reports. Records of these activities, access to ACEHR meeting materials, and additional details can be found on the NEHRP website at https://www.nehrp.gov/committees/index.htm.

Interagency Coordinating Committee Responses to ACEHR Recommendations

The ACEHR provided several observations and recommendations regarding NEHRP activities to the NIST Director, as the Interagency Coordinating Committee Chair, in FY 2017. The full text of the recommendations and corresponding responses from the NEHRP agencies are available on the NEHRP website.[9]

[9] See https://nehrp.gov/pdf/2016ACEHRReportFinal.pdf , https://nehrp.gov/pdf/11Sept2017_Final_ACEHRReport%20pg11%20fixed.pdf, and https://nehrp.gov/pdf/2017%20ACEHR%20report%20agency%20responsesFINAL_05-8-19.pdf

Executive Order (EO) 13717: *Establishing a Federal Earthquake Risk Management Standard*, was released on February 2, 2016.[10] This EO mandated NIST to lead the Interagency Committee on Seismic Safety in Construction (ICSSC), to lead the development and maintenance of ICSSC guidelines to assist the Federal agencies with implementing earthquake risk reduction measures in their construction programs, and to issue guidance to federal agencies to implement policies and standards to improve earthquake resilience of the federally-controlled building stock. In FY 2017, NIST published NIST TN 1922: *ICSSC Recommended Practice (RP 9): Implementation Guidelines for Executive Order 13717: Establishing a Federal Earthquake Risk Management Standard*. NIST will continue to report the progress of the applicable federal agencies in initiating and maintaining their compliance with the EO.

4.2 Advanced National Seismic System (USGS)

The ANSS is an effort led by the USGS to support, coordinate, and modernize earthquake monitoring nationwide. The system includes a national scale "backbone" seismic network, the National Earthquake Information Center, 11 partner-operated regional networks, and the National Strong Motion Project. The latter for recording strong, potentially damaging, earthquake shaking on the ground and in structures. As a result of substantial improvements to data recording and transmission capabilities, station coverage, and methods for rapid analysis, the ANSS now typically reports on domestic earthquakes large enough to be felt by humans within minutes of their occurrence. In FY 2017, the number of ANSS-standard stations increased to 3,142.

Cooperating universities operate regional seismic networks in areas of higher seismic risk. Regional data are used to monitor active faults and ground shaking in much greater detail and accuracy than is possible with the national-scale network. Each regional seismic network maintains seismic stations and processes and distributes earthquake notification products (e.g. location, magnitudes, ShakeMap) using standards established by ANSS, ensuring uniform and authoritative reporting for the U.S. and its territories. 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. Approximately $9 million was provided in FY 2017 through established cooperative agreements with academic and other non-USGS institutions to support core partner activities in earthquake monitoring.

4.3 Global Seismographic Network (NSF and USGS)

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 nuclear test treaty monitoring), earthquake loss reduction, and research on earthquake sources and the structure and dynamics of the Earth. The GSN provides critical data for rapid and accurate characterization of large earthquakes (M7.0

[10] Exec. Order No. 13717, Establishing a Federal Earthquake Risk Management Standard, 81 FR 6405 (February 5, 2016) https://www.govinfo.gov/content/pkg/FR-2016-02-05/pdf/2016-02475.pdf

or greater) worldwide. GSN data ensure a USGS capability to characterize and model the tectonic and geologic aspects of the source for all potentially damaging earthquakes.

In FY 2017, 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.

4.4 Natural Hazards Engineering Research Infrastructure (NSF)

NHERI is the next generation of NSF support for a multi-user, natural hazards engineering research facility that replaced NEES (George E. Brown, Jr. Network for Earthquake Engineering Simulation) in 2015. NHERI is a distributed, national facility supported by 11 NSF awards that provides 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 enables the community to make research and educational advances collaboratively, contributing 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. Information on NHERI and the 13 awards is available at https://www.designsafe-ci.org/.

The NHERI RAPID facility will provide capabilities to conduct post-earthquake, rapid response field research with a variety of cutting-edge equipment, instrumentation, and data acquisition tools, software analysis tools for quantitative and qualitative processing, and training resources to engage the post-disaster research community. The facility began operations in September 2016 and is continuing to acquire new, major instrumentation. Operational field deployment is scheduled to commence in September 2018. The NHERI Computational Modeling and Simulation Center (SimCenter) provides the natural hazards engineering research community with access to the next generation of open-source, computational modeling and simulation software tools and user support needed to advance the Nation's capability to simulate the impact of natural hazards, including earthquakes. The tools supplied by the SimCenter are publicly available at https://www.designsafe-ci.org/. The NHERI NCO at Purdue University is the central hub of NHERI multi-hazards research, coordinating work at the various NHERI experimental facilities, forging national and international partnerships, and organizing education and outreach efforts, including a REU program and a Summer Institute for graduate students and early career faculty. In July 2017, the

NHERI NCO organized a research meeting between Japanese and U.S. researchers to discuss joint research opportunities that could benefit from the coordinated use of NHERI resources and Japan's three-dimensional full-scale earthquake testing facility (E-Defense shake table).

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

Appendix A – Activities to Promote Preparedness, Hazard Mitigation Efforts, and Resilience

A.1. FEMA supported state level activities that advance earthquake awareness, risk reduction, and mitigation practices.

In FY 2017, several states focused on hazard analysis activities to better understand their earthquake risk and be able to prioritize mitigation investments.

Alaska continued their Rapid Visual Screening (RVS) of schools to assess high-risk K-12 schools and assist school district officials and residents in prioritizing seismic mitigation efforts for their schools.

Idaho is working on development of an earthquake clearinghouse to be used during exercises and real-world events to gather and disseminate earthquake data.

Maine, with support from the Northeast States Emergency Consortium (NESEC), continued its HAZUS Multi-Hazard analysis for six counties, folding in the following state level data sets: prioritized state-owned and state-leased facilities; prioritized bridges to include scour-critical bridges; updated and prioritized dam inventory; and power outage information.

Missouri has conducted RVS for schools, which provides free seismic assessments to schools in high-risk zones to help them improve seismic resiliency.

New York, with support from Earthquake Engineering Research Institute (EERI), conducted an "immediate occupancy" level seismic assessment of the State Emergency Operations Center in Albany, NY. Implementation of mitigation measures based on findings are currently underway to ensure the facility remains operationally suitable following an earthquake event.

South Carolina collaborated with the **Georgia** Emergency Management Agency and Georgia National Guard to share data and estimations of damage/loss associated with border and near-border seismic activity, along with continued promotion of general earthquake hazard and risk awareness and further analysis through use of HAZUS.

The **Vermont** Geological Survey, with support from NESEC, ran a multi-hazard analysis which integrates landslide and slope instability hazard data with earthquake and flood hazard information for Addison County. Maps and data were delivered to the regional planning commissions and will contribute to town planning efforts.

ShakeOut drills test public response to an earthquake.

ShakeOut participation continues to be a key NEHRP activity conducted by participating states. The FY 2017 ShakeOut drill had over 19.8 million participants nationwide and 56 million people worldwide. Half of all U.S. ShakeOut regions saw increased participation in FY 2017.

Alabama also participated and used social media during ShakeOut to engage partner state agencies and citizens.

Mississippi participated in the Great Central U.S. ShakeOut with 266,000 participants and targeted grades K-5 to increase earthquake awareness and preparedness, supported by distribution of an earthquake preparedness kit totes.

Missouri participated and promoted ShakeOut through billboards placed in the southeast portion of the state.

South Carolina participated in the Great SouthEast ShakeOut with 330,000 participants and partnered with schools in the Tri-County area to build awareness.

Tennessee recognized the risk related to the New Madrid Seismic Zone and participated in the Great Central U.S. ShakeOut.

Vermont experienced a small earthquake in FY 2017 and used the resulting media attention to promote ShakeOut and highlight actions which people should take during an event.

Washington participated in ShakeOut and promotion efforts throughout the year resulting in a 14% increase in participants over FY 2016, including increases in low-English proficiency communities.

Training to build capacity and competency within each state.

Alabama worked with FEMA to update the Earthquake Annex to the State Emergency Operations Plan to look at how the state can provide support to neighboring states and build out a resource support plan and update the logistics annex.

Illinois has advanced mitigation and planning efforts through the HOPE Hospital Coalition, which formed in FY 2016, and strengthened implementation through NETAP FEMA P-767: *Earthquake Mitigation for Hospitals* training. These engagements have resulted in the improvement of earthquake understanding, updating mitigation/response plans, and mitigation implementation methods.

Missouri has trained nearly a thousand volunteers as part of their SAVE Coalition program, which deploys volunteer structural experts to disaster areas to quickly assess whether they are safe to inhabit. Field manuals for these volunteers were developed and distributed in FY 2017.

Puerto Rico pursued training under the QuakeSmart program. QuakeSmart is a FEMA NEHRP initiative to help businesses in at-risk earthquake communities implement earthquake mitigation actions.

South Carolina hosted a state-level earthquake program training that included a mitigation analysis of the greatest at-risk areas within the state and a state emergency operations center tabletop exercise utilizing a state-wide earthquake cluster scenario.

The U.S. **Virgin Islands** hosted several FEMA trainings to improve earthquake mitigation in key structures, including schools and hospitals. Outreach Process Partners (OPP) also developed an earthquake awareness public service announcement for the U.S. Virgin Islands.

Training for states also took place through NETAP with the support of ATC in 13 states/territories, as follows: Alaska, California, Colorado, Illinois, Indiana, Massachusetts,

Missouri, Nevada, Oklahoma, Oregon, Puerto Rico, Tennessee, and Washington. In addition, five national webinars with 6,846 total participants were hosted under NETAP.

Conducting outreach and education among communities that could be impacted by a seismic event also continues to be a focus of several states.

Indiana, with support from the Central U.S. Earthquake Consortium (CUSEC), used the "Quake Cottage", an earthquake simulator, to provide citizens with a safe, yet realistic, experience of the intense shaking that can occur during an earthquake and promoted key protective action messages.

Kentucky, with the support from OPP, developed an earthquake preparedness activity sheet for children.

Tennessee developed several outreach materials, secured TV and radio spots, and hosted community engagements at schools and community groups in the New Madrid Seismic Zone to bring attention to the risk.

Washington developed video material for earthquake preparedness that can be posted on various channels to increase exposure and hosted a Youth Video Contest to get students involved in preparedness.

The FY 2017 NEPM meeting in Oklahoma City was a key activity for many states and provided the opportunity to leverage knowledge and experience across states and receive training on key seismic issues. Included in this three-day event were presentations on fundamentals of developing an earthquake program, induced seismicity, and training on improving seismic performance of manufactured housing.

For information on all significant FEMA state assistance activities for FY 2017, please visit https://www.fema.gov/nehrp-grant-program.

A.2. USGS Support for Earthquake Monitoring and Targeted Research

Every year, the USGS issues a Program Announcement for competitive proposals for grants and cooperative agreements to support research in earthquake hazards, the physics of earthquakes, earthquake occurrence, and earthquake safety policy. In FY 2017, the USGS provided substantial support to state institutions, private companies and non-governmental organizations for earthquake monitoring and applied research. This external activity allows the USGS to efficiently accomplish its goals in assessing earthquake hazards, understanding the physics of earthquakes, monitoring earthquake occurrence, and informing earthquake safety policy. The partnerships developed from this support allows the USGS to draw on expertise and capabilities that complements and expands in-house proficiencies.

The following table lists by institution the funding assistance USGS provided in FY 2017 to organizations in 23 states and the District of Columbia. Result reports for every USGS-funded research project and monitoring effort are posted at https://earthquake.usgs.gov/cfusion/external_grants/research.cfm.

Institution	Principal Investigator(s)	Program Element	Project Title
University of Southern California	Greg Beroza & Yehuda Ben-Zion	General	SCEC-5 Southern California Earthquake Center support.)
Consortium of Organizations for Strong-Motion Observation Systems (COSMOS)	Wilfred Iwan, Robert Nigbor, Jamison Steidl, C.B. Crouse, Anthony Shakal	General	Improving the Quality and Dissemination of Measured Earthquake Ground Motions
University of NAVSTAR Consortium	Glen Mattioli & Charles Meertens	Earthquake Early Warning	Incorporating Real-time GNSS into ShakeAlert
University of Nevada Reno	Graham Kent & Ken Smith	Earthquake Early Warning	Earthquake Early Warning in Eastern California: Phase 2
University of Oregon	Douglas Toomey & Leland O'Driscoll	Earthquake Early Warning	Implementation and Development of US West Coast ShakeAlert 2017-2019
Central Washington University	Timothy Melbourne & Kevin Archer	Earthquake Early Warning	Production Real-time GNSS for ShakeAlert
University of Washington	Harold Tobin & Paul Bodin	Earthquake Early Warning	Implementation and Development of U.S. West Coast ShakeAlert 2017-2019
University of California Berkeley	Richard Allen, Douglas Dreger & Margaret Hellweg	Earthquake Early Warning	Implementation and Development of U.S. West Coast ShakeAlert 2017-2019
California Institute of Technology	Thomas Heaton & Egill Hauksson	Earthquake Early Warning	Implementation and Development of U.S. West Coast ShakeAlert 2017-2019
University of Nevada Reno	Rich Koehler & John Anderson	Intermountain West	2017 Working Group on Nevada Seismic Hazards
Utah Geological Survey	Steve Bowman	Intermountain West	Detailed Mapping of the Wasatch Fault Zone, Utah and Idaho –Using New High-Resolution LiDAR Data
California Institute of Technology	Robert Clayton	Southern California	Analysis of a New Broadband Seismic Survey Across the San Bernardino Basin to Determine Velocity and Structure
University of Utah	Fan-Chi Lin	Southern California	Analysis of a New Broadband Seismic Survey Across the Los Angeles Basin
University of Nevada Reno	William Hammond	Intermountain West	Robust Estimation of Fault Slip, Block Rotation and Off-Fault Strain Rates in the Walker Lane from GPS Data
New Mexico Institute of Mining and Technology	Mark Murray	Northern California	Assessing Crustal Deformation in the San Francisco Bay Area: Collaborative Research with the U.S. Geological Survey, Menlo Park

Institution	Principal Investigator(s)	Program Element	Project Title
Harvard University	Miaki Ishii	Central and Eastern U.S.	Digitization of Harvard Analog Seismograms from 1933 to 1953 with a Focus on Caribbean Earthquakes
Harvard University	John Shaw	Southern California	Activity and earthquake potential of the Wilmington blind thrust, Los Angeles, CA: Collaborative Research with Harvard University and the University of Southern California
University of Southern California	James Dolan	Southern California	Activity and earthquake potential of the Wilmington blind thrust, Los Angeles, CA: Collaborative Research with Harvard University and the University of Southern California
Stanford University	George Hilley	Northern California	Automated fault mapping of the North America-Pacific plate boundary using airborne laser swath mapping (ALSM) data
Virginia Tech	Russell Green & Adrian Rodriquez-Marek	National	Accounting for Epistemic Uncertainty in Site Effects in PSHA
University of Nevada Reno	Steven Wesnousky	Intermountain West	Detailed Mapping of the Little Valley Fault, Reno-Carson, Nevada
Stanford University	Eric Dunham	Earthquake Physics	Thermomechanical Earthquake Cycle Simulations
San Diego State University	Shuo Ma	Engineering Seismology and Impacts	Further Validation of a Dynamic Earthquake Model to Produce Realistic Near-Field Ground Motion
University of Wisconsin Madison	Hiroki Sone	Earthquake Physics	2D p-wave tomography and its temporal changes along a rough laboratory fault undergoing stick-slip cycles
Tufts University	Robert Viesca	Earthquake Physics	Models for aseismic fault slip in response to fluid injection
Indiana University	Michael Hamburger & Scott Robeson	Engineering Seismology and Impacts	Near Real-Time Assessment of Seismically Induced Landslides
University of California Los Angeles	Jonathan Stewart	National	Shear Wave Velocity Profile Database and Its Application for Analysis of Non-Ergodic Site Amplification Effects
Lettis Consultants International, Inc.	Ivan Wong	Earthquake Physics	Analyses of Strong Motion and Broadband Data of Induced Earthquakes in Kansas, Oklahoma, and Texas and Development of a Ground Motion Prediction Model for Induced Earthquakes

Institution	Principal Investigator(s)	Program Element	Project Title
University of Memphis	Roy Van Arsdale, Daniel Larsen & Ronald Counts	Central and Eastern U.S.	Quaternary Displacement Rates on the Meeman-Shelby Fault and Joiner Ridge, Second Year: Collaborative Research between the University of Memphis and U.S. Geological Survey
Fugro Consultants, Inc.	C. Mendoza, J. Turner & D. O'Connell	Central and Eastern U.S.	Ground Motion Characterization and Site-Specific IMASW Vs-Depth Measurements at CEUS seismic stations: The 2011 Prague, Oklahoma earthquake
California State University East Bay	Mitchell Craig	Northern California	Site characterization in the Sacramento-San Joaquin Delta using seismic surface wave and reflection methods
Smith College	John Loveless	Pacific Northwest and Alaska	Sparsity-based estimates of slow slip distributions in Cascadia
Oregon State University	Andrew Meigs	Pacific Northwest and Alaska	A comparative analysis of onshore-offshore paleoseismic archives: Collaborative Research with Oregon State University and the University of Rhode Island
University of Rhode Island	Simon Engelhart	Pacific Northwest and Alaska	A comparative analysis of onshore-offshore paleoseismic archives: Collaborative Research with Oregon State University and the University of Rhode Island
Woods Hole Oceanographic Institution	Jeffrey McGuire	Pacific Northwest and Alaska	3D Shear Velocity Structure in the Mendocino Triple Junction Region
AECOM Technical Services, Inc.	Mehrdad Hosseini, Paul Somerville & Hong Kie Thio	Central and Eastern U.S.	Improving Regional Attenuation Models in the CUS by Using Radiation Pattern Correction, Independent Estimation of Geometrical Spreading Decay Rates, and Independent Estimation of Receiver Terms from the Receiver Functions
Virginia Polytechnic Institute and State University	Martin Chapman	Central and Eastern U.S.	Seismological Investigation of Active Faults in the Central Virginia Seismic Zone
Columbia Lamont University	Heather Savage	General	Workshop Proposal: Scientific Exploration of Induced SeisMicity and Stress (SEISMS)
Miami University	Michael Brudzinski	Pacific Northwest and Alaska	Improved Characterization of Slow Slip in Cascadia by Stacking GPS on Tremor Times: Collaborative Research with University of Alaska Fairbanks and Miami University
University of Alaska Fairbanks	Stephen Holtkamp	Pacific Northwest and Alaska	Improved Characterization of Slow Slip in Cascadia by Stacking GPS on Tremor Times: Collaborative Research with University of Alaska-Fairbanks and Miami University

Institution	Principal Investigator(s)	Program Element	Project Title
Boise State University	Lee Liberty	Central and Eastern U.S.	Seismic profiling of faults related to the 1886 Charleston, South Carolina earthquake: A collaborative US Geological Survey proposal
University of Memphis	Ricardo Taborda	Engineering Seismology and Impacts	Characterization of ground motion variability due to the presence of the built environment
California Institute of Technology	Domniki Asimaki	National	Sensitivity of nonlinear site amplification factors to the models used to simulate and constrain rare events
San Diego State University	Kim Olsen	Southern California	Turning and Validating High-Frequency Ground Motion Variability in the SDSU Broadband Method
Clemson University	Qiushi Chen & Charng Hsein Juang	Engineering Seismology and Impacts	Multiscale random field-based probabilistic regional liquefaction mapping
The University of Memphis	Robert Smalley & Randel Cox	Central and Eastern U.S.	Testing for paleoseismic signals in the geomorphology of Quaternary terraces of the upper Mississippi embayment using LIDAR and geologic data
Oregon State University	Anne Trehu	Pacific Northwest and Alaska	The relationship between crustal structure and earthquake activity on the central Cascadia continental margin in 3D
Stanford University	Jack Baker	Engineering Seismology and Impacts	Spatial correlation of ground motion characteristics for regional hazard and risk: regionalization and non-stationarity
University of Montana	Michael Stickney & Jeffrey Lonn	Intermountain West	Investigation of late Quaternary fault scarps along the Bitterroot Fault in western Montana
Boise State University	Lee Liberty	Intermountain West	Seismic profiling in downtown Salt Lake City: Mapping the Wasatch fault with seismic methods from a land streamer
Brigham Young University	Kevin Franke	Intermountain West	Probabilistic Liquefaction Triggering and Lateral Spread Hazard Maps for Davis, Weber and Salt Lake Counties, Utah: Collaborative Research with University of Utah and Brigham Young University
University of Utah	Steven Bartlett	Intermountain West	Probabilistic Liquefaction Triggering and Lateral Spread Hazard Maps for Davis, Weber and Salt Lake Counties, Utah: Collaborative Research with University of Utah and Brigham Young University

Institution	Principal Investigator(s)	Program Element	Project Title
InfraTerra	Ozgur Kozaci	Northern California	Assessing the timing of the penultimate and pre-penultimate earthquakes of the San Andreas fault Peninsula Segment using dendrochronology: Collaborative Research with U.S. Geological Survey
Miami University	Michael Brudzinski	Earthquake Physics	Investigating Induced Seismicity Associated with Hydraulic Fracture Stimulations in Oklahoma
University of Utah	James Pechmann	National	Numerical Testing of a New Procedure to Determine Unbiased Seismicity Rates from Earthquake Catalogs
Utah Geological Survey	Greg McDonald, Adam Hiscock & Michael Hylland	Intermountain West	Paleoseismic Investigation of the Levan and Fayette Segments of the Wasatch Fault Zone, Juab and Sanpete Counties, Utah
Cornell University	Geoffrey Abers	Pacific Northwest and Alaska	Earth structure effects on wave propagation of the damaging 2016 M7.1 Iniskin Alaska earthquake and other in-slab earthquakes
University of California Riverside	Gareth Funning	Northern California	Dynamic rupture modeling on the Hayward Fault, northern California – estimating coseismic and postseismic hazards of partially creeping faults. Collaborative research: California State University, Northridge, and University of California, Riverside
California State University Northridge	Julian Lozos	Northern California	Dynamic rupture modeling on the Hayward Fault, northern California – estimating coseismic and postseismic hazards of partially creeping faults. Collaborative research: California State University, Northridge, and University of California, Riverside
Utah Geological Survey	Steve Bowman, Greg McDonald, Adam Hiscock	Intermountain West	Detailed Mapping of the Holocene- and Late Quaternary-Active Traces of the East and West Cache Fault Zones, Cache Valley, Utah and Idaho—Using New High-Resolution LiDAR Data to Reduce Earthquake Risk
University of Rhode Island	Simon Engelhart	Pacific Northwest and Alaska	Paleogeodesy of a non-persistent rupture boundary at Sitkinak Island, Alaska: Collaborative Research with University of Rhode Island and U.S. Geological Survey
University of Nevada Reno	Ilia Zaliapin	Earthquake Physics	A systematic approach for discriminating between tectonic and induced earthquake clusters: Collaborative Research with University of Nevada Reno and University of Southern California

Institution	Principal Investigator(s)	Program Element	Project Title
University of Southern California	Yehuda Ben-Zion	Earthquake Physics	A systematic approach for discriminating between tectonic and induced earthquake clusters: Collaborative Research with University of Nevada Reno, and University of Southern California
University of Michigan	Dimitrios Zekkos & Marin Clark	Engineering Seismology and Impacts	Characterization of landslides and rock mass strength leveraging the 2015 Mw 6.5 Lefkada earthquake in Greece
Lettis Consultants International, Inc.	Robert Givler & John Baldwin	Northern California	Paleoseismic Investigation of the Southernmost Rodgers Creek Fault at Cline Vineyards, Sonoma, California
University of Memphis	Shahram Pezeshk	National	A New Model for Vertical to Horizontal Response Spectral Ratios for Central and Eastern North America
Utah State University	Anthony Lowry	Earthquake Physics	Toward Earthquake System Science: Western U.S. Lithospheric Stress/Strain Partitioning of Mantle Dynamics
University of Nevada Reno	John Anderson & Glenn Biasi	National	Slip Rate Dependence of Displacement Scaling Relationships
University of Nevada Reno	John Anderson	National	Slip Rate Dependence of Displacement Scaling Relationships
Lettis Consultants International, Inc.	Jeffrey Unruh & Ivan Wong	Northern California	Seismotectonic Characterization of the Coast Range-Sierran Block Boundary Zone, California
Lettis Consultants International, Inc.	Brian Gray & John Baldwin	Central and Eastern U.S.	Geophysical and Paleoseismic Investigation of the Kingtown Lineament along the Big Creek fault zone, Phillips County, Arkansas: Collaborative research with Millsaps College and Lettis Consultants International, Inc.
Millsaps College	James Harris	Central and Eastern U.S.	Geophysical and Paleoseismic Investigation of the Kingtown Lineament along the Big Creek fault zone, Phillips County, Arkansas: Collaborative research with Millsaps College and Lettis Consultants International, Inc.
Elizabeth Hearn	Elizabeth Hearn	Earthquake Physics	Evolution of Pore Pressures, Stresses and Seismicity due to Wastewater Injection in Southern Kansas: Numerical Models
Lawrence Livermore National Laboratory (LLNL)	Tom Guilderson	General	Interagency agreement (IAA) between the U.S. Geological Survey (USGS) and the U.S Department of Energy Lawrence Livermore National Lab (LLNL) for analyses performed at LLNL's Center for Accelerator Mass Spectrometry

A.3. NIST Disaster Resilience Research Grants for Earthquake Engineering

In FY 2017, NIST provided funding support to five organizations (listed below) to conduct earthquake-related research as part of the Disaster Resilience Research Grants Program:

- **Stanford University (Stanford, California)**
  Seismic Assessment, Retrofit Strategies and Policy Implications for Vulnerable Existing Steel Buildings - For the development and application of a comprehensive method to assess the safety risks of earthquake-vulnerable tall steel buildings.
- **University of Colorado (Boulder, Colorado)**
  Integrating Aging Effects in Performance-Based Seismic Design and Assessment of Reinforced Concrete Structures - For a study of the effects of aging on the mechanical properties of concrete and steel, and on the overall seismic performance of reinforced concrete.
- **University of Michigan (Ann Arbor, Michigan)**
  Resilience of Steel Moment Frame Systems with Deep Slender Column Sections - For a study of the performance during seismic events of deep slender column sections within a steel special moment frame structure (where beams, columns and beam-column connections are designed to be more earthquake resilient).
- **University of Texas at San Antonio (San Antonio, Texas)**
  Decision-Oriented Column Simulation Capabilities for Enhancing Disaster Resilience of Reinforced Concrete Buildings - For the development of a new generation of computer simulation models that will characterize the impact of severe earthquake conditions on reinforced concrete columns.
- **University of Washington (Seattle, Washington)**
  Liquefaction-Targeted Ground Motion Parameters - For a study to better understand and define the characteristics of soil liquefaction (where a saturated or partially saturated soil loses strength and stiffness in response to earthquake shaking) to enable more accurate predictions of hazards to structures and infrastructure lifelines.

Appendix B. Cooperation with Other Relevant Organizations

Subcommittee on Disaster Reduction (SDR) is a Federal interagency body of the National Science and Technology Council (NSTC) that advises and assists the Committee on Environment, Natural Resources, and Sustainability (CENRS) and the NSTC on policies, procedures, plans, issues, scientific developments, and research needs to facilitate and promote disaster mitigation, preparedness, response, and recovery. Representatives of the NEHRP agencies participate in SDR meetings and provide briefings on program developments. The SDR serves as a forum where NEHRP agencies can reach out to and coordinate with other Federal agencies doing work related to NEHRP goals and objectives.

Building Seismic Safety Council (BSSC) Under the sponsorship of FEMA, the BSSC, a branch of the National Institute of Building Sciences, continued managing the development of the *2020 NEHRP Recommended Seismic Provisions,* proposing many significant technical changes in model building codes and standards, including the ASCE/SEI 7-22: *Minimum Design Loads for Buildings and Other Structures* and the 2024 International Building Code. The BSSC also managed Project 17, which is intended to facilitate the coordination of practicing engineers and USGS scientists engaged in formulating the rules by which next-generation seismic design value maps will be developed as a basis for structural design.

Applied Technology Council (ATC) supported significant training through the NETAP program and helped develop a new training course for the FEMA P-1000, *Safer, Stronger, Smarter: A Guide to Improving School Natural Hazard Safety* (June 2017) and *Improving Earthquake Performance of Manufactured Homes* (1.5-hour in-person course or webinar).

Central U.S. Earthquake Consortium (CUSEC), working with the National Emergency Management Association and in partnership with FEMA and the USGS during FY 2017, developed a standardized framework for deployment of post-disaster safety assessment and geological survey support teams.

Federal Alliance for Safe Homes (FLASH) created and developed consumer-focused resources for FEMA including videos and brochures; promoted building code adoption and enforcement to more than 225 elected officials at all levels of government.

Cascadia Region Earthquake Workgroup (CREW) coordinated with earthquake program coordinators from Oregon and Washington to work with more than 100 state, tribal, and local emergency managers and more than 300 community members in crafting a new strategy on how to effectively implement EEW systems in the Pacific Northwest.

Northeast States Emergency Consortium (NESEC) prepared HAZUS Multi-Hazard Earthquake Analyses for Maine, Massachusetts, Vermont, and the City of Boston in support of earthquake hazard awareness, mitigation, and Threat and Hazard Identification and Risk Assessment.

Southern California Earthquake Center (SCEC) at the University of Southern California (USC), with support from NSF and the USGS conducts research on earthquake hazards and related topics in southern California. With FEMA support SCEC coordinates ShakeOut participation recruitment and resource development with participating states, Indian tribes, territories, and multi-state regions.

Earthquake Country Alliance (ECA) leveraged local alliances in Southern California and the Bay Area which present three to four public workshops a year with science, mitigation, preparedness presentations along with networking and presentation skills trainings. ECA worked with the California Office of Emergency Services to organize Emergency Preparedness for People with Disabilities, a workshop held during Abilities Expo events held annually in the Bay Area and Los Angeles..

Western States Seismic Policy Council (WSSPC) members adopted five policy recommendations relating to earthquake monitoring networks, EEW systems, mitigation of unreinforced masonry buildings, seismic design and construction of new schools, and improving tsunami public education.

Appendix C. Major Earthquakes in FY 2017[11]

C.1. Global Seismicity Statistics

Globally there were 6,360 earthquakes with a M4.5 or greater in FY 2017. This worldwide activity is slightly lower than the 20-year average of 6,671 annually. There were nine earthquakes worldwide of M7.0 or greater in FY 2017, which is also lower than an average of 14 M7.0 or greater earthquakes per year over the last 40 years.

C.2. United States Earthquakes

The largest earthquakes in the U.S. during FY 2017 were a M6.8 earthquake along the western Aleutian Islands on June 2, and a M6.6 earthquake off the coast of northern California on December 8. Due to their locations in remote and sparsely populated areas, these events caused no casualties or damage, nor did they generate a tsunami.

In the contiguous U.S. during FY 2017, the most notable activity was a M5.8 earthquake near Lincoln, Montana on July 06, which was followed five minutes later by a M5.0 aftershock. Although widely felt these earthquakes caused no reportable damage. A vigorous earthquake swarm occurred near Soda Springs, Idaho, which resulted in 33 earthquakes in the range of M4.0 to M5.3 with the largest event occurring at the beginning of the sequence on September 2. In the central U.S., seismicity rates in Kansas, Oklahoma and Texas continued to decline in FY 2017, with six earthquakes of M4.0-4.3 in Kansas, Oklahoma and Texas, compared to 21 M4.0 or greater events in FY 2016, including three earthquakes in the M5 range in Oklahoma. The USGS recorded a total of 322 M3.0-4.3 in the region compared to 672 M3.0 or greater earthquakes in FY 2016.

C.3. Major Foreign Earthquakes

Mexico was struck by two damaging earthquakes in late FY 2017. A M8.2 earthquake struck off the coast in Chiapas, Mexico on September 8. Eleven days later a M7.1 earthquake occurred in south-central Mexico. This second event resulted in 370 deaths and over 6,000 injuries within the region and caused extensive damage in Mexico City some 75 miles to the north, due in part to amplification of ground motions in the sedimentary basin that underlies the city. The USGS responded by helping to coordinate a U.S. multi-agency scientific response to the earthquake; providing aftershock forecasts at the request of the USAID Office of Foreign Disaster Assistance to provide situational awareness to the Search and Rescue and Disaster Assistance Response Team deployed to the region; and participating in an EERI reconnaissance team who explored technical and social science aspects of the Mexican Seismic Alert System during its activation.

A M7.8 earthquake struck near the northeastern shore of New Zealand's South Island on November 13. The earthquake was of unprecedented complexity, involving over 20 distinct fault

[11] Earthquake location and magnitude information in this appendix is taken from the USGS National Earthquake Information Center, recognized worldwide as the authoritative source.

segments, causing widespread landslides in the area of strong shaking, and triggering accelerated aseismic slip on the hazardous subduction zone east of the North Island. Damage to the built environment, deaths, and injuries were reported within the region. USGS landslide experts worked with New Zealand colleagues to analyze the pattern of landslides; this collaboration resulted in improved techniques for providing rapid estimates of landslide extent and severity immediately following major earthquakes.

Appendix D. List of Acronyms and Abbreviations

ACEHR	Advisory Committee on Earthquake Hazards Reduction
AEL	annualized earthquake loss
ANSS	Advanced National Seismic System
AOAM	Agency Operations and Award Management
ASCE	American Society of Civil Engineers
ATC	Applied Technology Council
BSSC	Building Seismic Safety Council
CENRS	Committee on Environment, Natural Resources, and Sustainability
CEUS	Central and Eastern U.S.
CREW	Cascadia Region Earthquake Workgroup
CUSEC	Central United States Earthquake Consortium
DOE	Department of Energy
ECA	Earthquake Country Alliance
EERI	Earthquake Engineering Research Institute
EEW	Earthquake Early Warning
EHP	Earthquake Hazards Program
ENH	Engineering for Natural Hazards
EO	Executive Order
FEMA	Federal Emergency Management Agency
FLASH	Federal Alliance for Safe Homes
FY	fiscal year
GSN	Global Seismographic Network
HAZUS	Hazards U.S.
IRIS	Incorporated Research Institutions for Seismology
M	magnitude
$M	(dollars) million
NCO	(NSF) Network Coordination Office
NEES	George E. Brown, Jr. Network for Earthquake Engineering Simulation
NEHRP	National Earthquake Hazards Reduction Program
NEPM	National Earthquake Program Managers
NESEC	Northeast States Emergency Consortium

NETAP	National Earthquake Technical Assistance Program
NHC	Natural Hazards Center
NHERI	(NSF) Natural Hazards Engineering Research Infrastructure
NIST	National Institute of Standards and Technology
NSF	National Science Foundation
NSTC	National Science and Technology Council
OMB	Office of Management and Budget
OSTP	White House Office of Science and Technology Policy
PACT	Performance Assessment Calculation Tool
PBSD	performance-based seismic design
PCWG	(NEHRP) Program Coordination Working Group
PEER	Pacific Earthquake Engineering Research Center
PUC	Provisions Update Committee
R&D	research and development
RAPID	(NSF) Rapid Response Research funding mechanism
RCN	research coordination network
REU	Research Experiences for Undergraduates
RVS	Rapid Visual Screening
S&E	salaries and expenses
SCEC	Southern California Earthquake Center
SCEMD	South Carolina Emergency Management Division
SDC	Seismic Design Category
SDO	Standards Development Organization
SEI	Structural Engineering Institute
SDR	Subcommittee on Disaster Reduction
SimCenter	(NSF) Computational Modeling and Simulation Center
UCERF	Uniform California Earthquake Rupture Forecast
US	United States
USGS	United States Geological Survey
WSSPC	Western States Seismic Policy Council