Annual Report of the National Earthquake Hazards Reduction Program

For Fiscal Year 2016

May 2019

This report about the National Earthquake Hazards Reduction Program (NEHRP) during fiscal year (FY) 2016 is submitted to Congress by the NEHRP 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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Executive Summary

This is the annual report of the National Earthquake Hazards Reduction Program (NEHRP) covering FY 2016[1], presented by the NEHRP Interagency Coordinating Committee. This report, required by Public Law 108–360, describes the FY 2016 activities of the NEHRP agencies and their progress toward reducing the impacts of future earthquakes in the United States. This report also summarizes actual NEHRP-related program budgets by agency for FY 2017 and program budgets requested by each agency for FY 2018.

The four federal agencies participating in the NEHRP Interagency Coordinating Committee are the Federal Emergency Management Agency (FEMA), the National Institute of Standards and Technology (NIST), the National Science Foundation (NSF), and the U.S. Geological Survey (USGS). NIST serves as the NEHRP lead agency. The NEHRP agencies have distinct roles and responsibilities that are mutually supportive.

The NEHRP Interagency Coordinating Committee is composed of the Administrator of FEMA, the Directors of NIST, NSF, and USGS, and the Directors of the White House Office of Science and Technology Policy (OSTP) and the Office of Management and Budget (OMB). The Director of NIST chairs the Interagency Coordinating Committee.

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. The NEHRP Strategic Plan (October 2008) sets forth three NEHRP strategic goals: (A) Improve understanding of earthquake processes and impacts; (B) Develop cost-effective measures to reduce earthquake impacts on individuals, the built environment, and society-at-large; and (C) Improve the earthquake resilience of communities nationwide. In support of the three NEHRP strategic goals, some of the significant NEHRP activities of FY 2016 covered in this report are listed briefly below.

Goal A, Improve understanding of earthquake processes and impacts.

> NEHRP-supported research led to new design and construction methods for light-frame residential housing, providing improved resistance to damage during earthquakes. The research focused on developing new design methods for uni-body frame buildings with enhanced strength coupled with isolation systems to reduce transmission of shaking between the foundation and superstructure. (NSF)
>
> NEHRP advanced the monitoring and understanding of "induced" seismicity associated with the deep-well injection of wastewaters commonly used in the recovery of oil and natural gas by hydro-fracking techniques. A result of this research may be deep-well pumping protocols that will reduce the likelihood of induced earthquakes. (USGS)

[1] This report covers FY 2016 as defined by the Federal Government, a period that began on October 1, 2015, and ended on September 30, 2016.

NEHRP began developing analytical tools and analyzing global seismicity data, working toward an automated capability for forecasting the expected size and frequency of aftershocks that occur after large earthquakes. (USGS)

NEHRP 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. (NSF)

Goal B. Develop cost-effective measures to reduce earthquake impacts on individuals, the built environment, and society at large.

NEHRP developed and published a set of application examples and training materials to support application and usage by design and construction communities of the 2015 edition of the *NEHRP Recommended Seismic Provisions for New Buildings and Other Structures (NEHRP Recommended Provisions)*. These provisions are used in the revision of national model building codes and standards adopted throughout the United States. (FEMA, NIST)

NEHRP initiated the next update cycle for the 2020 *NEHRP Recommended Provisions* and supported a national committee of experts to re-examine the basis for the seismic design value maps and the rules under which the maps are produced. (FEMA, NIST)

NEHRP developed a new, one-year forecast for natural and human-induced seismicity in the Central and Eastern United States. This new product reflects the short-term hazard caused by earthquakes induced by wastewater injection. (USGS)

In collaboration with the building design community, NEHRP adopted new seismic hazard estimates into engineering design maps and the 2018 International Building and Residential Codes. (FEMA, NIST, USGS)

NEHRP continued to develop and publish design guidelines to support practicing structural engineers and enhance education. (NIST)

Performance-based seismic design (PBSD) has emerged as an effective means of designing structures to resist earthquake ground motions while allowing structural engineers more latitude in their design approaches. NEHRP continued its research into improved PBSD approaches by completing a study involving buckling restrained braces and conducting a preliminary study of reinforced concrete special moment frames. (NIST)

Goal C. Improve the earthquake resilience of communities nationwide.

NEHRP worked with other federal agencies to increase risk awareness and resiliency for the federal community. On February 2, 2016, the White House issued Executive Order (EO) 13717: Establishing a Federal Earthquake Risk Management Standard.[2] NIST coordinated interagency input for the implementation guidelines for the EO, working with the Executive

[2] See https://obamawhitehouse.archives.gov/the-press-office/2016/02/02/executive-order-establishing-federal-earthquake-risk-management-standard

Office of the President to draft and finalize the guidelines, which are posted on the NEHRP website. (NIST)

In June 2016, FEMA sponsored "Cascadia Rising 2016", a four-day, large-scale exercise to test response and recovery capabilities in the wake of a 9.0 magnitude (M9.0) Cascadia Subduction Zone earthquake and tsunami. The exercise involved more than 20,000 participants in the Pacific Northwest including emergency managers at local, state, tribal and federal levels, military commands, and private sector and non-governmental organizations. NEHRP agencies participated in the scenario planning and execution of the exercise. (FEMA, USGS)

NEHRP continued to develop the nation's earthquake early warning (EEW) capability to quickly and automatically identify and characterize an earthquake after it begins, and to deliver warnings within seconds to the general public and to operators of critical systems that may experience damaging shaking. (USGS)

Section 1 - Introduction

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

Public Law 108–360 requires that the Interagency Coordinating Committee, submit an annual report to Congress on NEHRP budgets and activities. The Interagency Coordinating Committee is submitting this annual report through NEHRP agency leadership, covering FY 2016, pursuant to that requirement.

The FY 2016 NEHRP annual report provides an overview of NEHRP agency budgets; a description of the activities and results of NEHRP during the previous year, including an assessment of the effectiveness of NEHRP in furthering the goals established in the NEHRP Strategic Plan; a description of the extent to which NEHRP has incorporated the recommendations of the Advisory Committee on Earthquake Hazards Reduction (ACEHR); and a description of activities carried out by NEHRP agencies and contribute to NEHRP, but are not included in NEHRP; and a summary of related activities that support NEHRP goals. This report and prior NEHRP annual reports are available at www.nehrp.gov/about/reports.htm.

In 2016, the Federal Government took several steps to increase earthquake risk awareness and resiliency within the federal community. The U.S. Government Accountability Office published a report that identified additional actions that needed to be taken to diagnose and mitigate seismic risks to federal buildings and implement an early warning system. In addition, EO 13717 – *Establishing a Federal Earthquake Risk Mitigation Standard,* was issued and directed the Federal Government to take proactive steps to enhance the resilience of buildings that are owned, leased, financed, or regulated by the Federal Government.

NEHRP agencies focused on the importance of capturing, preserving, and sharing data to better inform structural and social resiliency in the event of an earthquake. NSF supported the development of software to better capture and document assessment data from the field. Data preserved post-event can enable scientific researchers to learn more about the nature of the disaster, catalogue the degree of the damage incurred, and help guide future research directions. For example, the M6.4 southern Taiwan earthquake that occurred near the city of Tainan, Taiwan, on February 5, 2016 caused severe damage, partial collapse, and full collapse of low-to-midrise reinforced concrete buildings. NSF supported post-disaster, rapid-response researchers from the University of Washington and Purdue University to gather perishable building-response data. The research team assembled a comprehensive data set that can be used by other researchers and practitioners.

[3] 42 U.S.C. § 7702.

Continued assessment and improvement of seismic building codes and supporting guidance was another priority for 2016, as the new update cycle for the 2020 *NEHRP Recommended Provisions* began. In addition, the FEMA funded Project 17 Committee, which includes FEMA, NIST, and USGS representatives as well as non-federal stakeholders, continued developing the next generation of seismic hazard maps for the U.S.

The sharing of data and resources across the earthquake community, including the Federal Government and private sector, is critical for continued improvement of earthquake resiliency in the United States. Accurate assessments of seismic risk and the tools to improve the resiliency of both structures and communities are necessary. 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 United States and abroad.

Section 2 - Program Budgets

Public Law 108–360 requires that NEHRP annual reports include, for each agency participating in the program and for each program activity defined in the legislation, the program budget by agency for the current FY (i.e., the year following that which is covered in the report) and the proposed program budget by agency for the next FY. *See* 42 U.S.C. § 7704(a)(4). The *Strategic Plan for the National Earthquake Hazards Reduction Program, Fiscal Years 2009–2013* (http://nehrp.gov/pdf/strategic_plan_2008.pdf), published in October 2008[4], defined three major goals for NEHRP that encompass all but one of the program activities defined in Public Law 108–360. The remaining activity, which concerns the development, operation, and maintenance of NEHRP facilities, was also incorporated 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 effective measures for earthquake hazards 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 ANSS, NHERI, and the GSN. 42 U.S.C. § 7704(a)(2)(D).

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

Program budgets by agency for FY 2016 are presented in Table 2.2. Program budgets by agency for FY 2017 are presented in Table 2.3, which shows 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 2018. Funding for the development, operation, and maintenance of NEHRP facilities supports the Advanced National

[4] Strategic Plan progress is limited by the appropriated funding 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.

Seismic System (ANSS), the earthquake engineering portion of the Natural Hazards Engineering Research Infrastructure (NHERI), and the Global Seismographic Network (GSN).

2.1 NEHRP Enacted FY 2016 and FY 2017 Budgets by Agency and Strategic Goal

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

Table 2.2 – *NEHRP AGENCY BUDGETS for FY 2016*

Strategic Goal	FY 2016 Funds Allocated to Goal ($M)[1]				
	FEMA[2]	NIST[3]	NSF[4]	USGS[5]	**Total**
Goal A: Improve understanding of earthquake processes and impacts.	0.1	0.3	50.7	11.6	**62.7**
Goal B: Develop cost-effective measures to reduce earthquake impacts on individuals, the built environment, and society at large.	4.6	4.6		2.4	**11.6**
Goal C: Improve the earthquake resilience of communities nationwide.	3.8	0.3		16.3	**20.4**
Develop, operate, and maintain NEHRP facilities:					
ANSS				30.2	**30.2**
GSN			3.5	6.5	**10.0**
Total:	**8.5**	**5.2**	**54.2**	**67.0**	**134.9**

Notes on Table 2.2:

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

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

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

[4] NSF FY 2016 budget supported all NEHRP-related activities, excluding Agency Operations and Award Management (AOAM). Budget included support for the NSF portion of the GSN ($3.5M) and the earthquake engineering portion of the Natural Hazards Engineering Research Infrastructure (NHERI), but excluded EarthScope activities.

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

Table 2.3 lists the FY 2017 NEHRP budgets, by strategic goal, for the NEHRP agencies: FEMA, NIST, NSF, and USGS.

Table 2.3 – *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	13.6	**64.7**
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		17.3	**21.4**
Develop, operate, and maintain NEHRP facilities:					
ANSS				30.2	**30.2**
GSN			3.5	6.5	**10.0**
Total:	**8.5**	**5.2**	**54.2**	**71.0**	**138.9**

Notes on Table 2.3:

[1] Enacted budgets are rounded to the nearest $0.1M. 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 NEHRP Secretariat (Lead Agency) and NIST Earthquake Risk Reduction in Buildings and Infrastructure research and development (R&D) Program activities. Budget included $1.3M of new Disaster Resilience Grant funding.

[4] NSF FY 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 Natural Hazards Engineering Research Infrastructure (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 ($6.5M).

2.2 NEHRP FY 2018 Budget Requests by Agency and Strategic Goal

Table 2.4 lists the FY 2018 NEHRP planning budgets for each agency by strategic goal. These are the figures included in the President's FY 2018 budget request to Congress.

TABLE 2.4 – *NEHRP AGENCY BUDGET REQUESTS for FY 2018*

Strategic Goal	FY 2018 Funds Requested or Anticipated for NEHRP Goals ($M)[1]				
	FEMA[2]	NIST[3]	NSF[4]	USGS[5]	**Total**
Goal A: Improve understanding of earthquake processes and impacts.	0.1	0.1	50.5	13.0	**63.7**
Goal B: Develop cost-effective measures to reduce earthquake impacts on individuals, the built environment, and society at large.	4.6	4.8		3.4	**12.8**
Goal C: Improve the earthquake resilience of communities nationwide.	3.8	0.3		15.6	**19.7**
Develop, operate, and maintain NEHRP facilities:					
ANSS				19.4	**19.4**
GSN			3.5	5.0	**8.5**
Total:	**8.5**	**5.2**	**54.0**	**56.4**	**124.1**

Notes on Table 2.4:

[1] Budgets are rounded to the nearest $0.1M. 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 2018 budget supported all NEHRP-related activities, including employee salaries and expenses (S&E).

[3] NIST requested FY 2018 budget supported all NEHRP-related activities, including NEHRP Secretariat (Lead Agency) and NIST Earthquake Risk Reduction in Buildings and Infrastructure R&D Program activities. Budget included $1.3M of new Disaster Resilience Grant funding.

[4] NSF requested FY 2018 budget supported 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 requested FY 2018 budget supported NEHRP-related activities, including the USGS EHP and the USGS portion of GSN ($5.0M).

Section 3 - NEHRP Highlights

This section summarizes major activity highlights and accomplishments of the NEHRP during FY 2016. The organization of this chapter follows that of the NEHRP strategic plan http://nehrp.gov/pdf/strategic_plan_2008.pdf). The strategic plan defines NEHRP in terms of broad strategic goals and more specific objectives and related strategic priorities. The goals are directly linked to the NEHRP activities defined in 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 not categorized by NEHRP agency but, rather, are cast in terms of collective progress toward NEHRP goals.

3.1 Goal A: Improve Understanding of Earthquake Processes and Impacts

Understanding how and why earthquakes occur, and what happens to our communities when they do, is an essential step in building the knowledge required to reduce the consequences of future earthquakes. For this reason, NEHRP supports basic research related to earthquakes in geoscience, engineering, and social science. The research supported and undertaken under Goal A provides a strong foundation for the development and implementation of practical earthquake risk-reduction measures pursued under the other strategic goals.

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

In FY 2016, 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.

Studies of Seismicity Induced by Wastewater Injection

The USGS released new maps and a report in FY 2016 that, for the first time, identify potential ground-shaking hazards from both human-induced and natural earthquakes. In the past, USGS maps only identified natural earthquake hazards. The new hazard model estimates how often and how strongly earthquake ground shaking could occur in the United States during calendar year 2016. The USGS chose the timeframe of one year because induced earthquake activity can increase or decrease with time and is subject to commercial and policy decisions that could change rapidly. This was the first one-year outlook for the nation's earthquake hazards, and is a supplement to existing USGS assessments that provide a 50-year forecast. The report shows that approximately 7 million people live and work in areas of the central and eastern U.S. (CEUS) with potential for damaging shaking from induced seismicity. Within a few portions of the CEUS, the chance of damage from all types of earthquakes is similar to that of natural earthquakes in high-hazard areas of California.

The USGS continued to study earthquakes in Oklahoma, Kansas, Texas, and Colorado that have been found to be caused by deep-well injection of wastewaters commonly used in the recovery of oil and natural gas by hydro-fracking techniques. Current studies aim to develop methods to forecast which types of injections in which geologic settings would be likely to induce or trigger earthquakes, to perform comprehensive studies at carefully selected field sites, and to establish procedures to adapt USGS National Seismic Hazard Maps to account for potential hazards from earthquakes induced in association with the production of oil and gas.

Aftershock Forecasting Beyond California

For many years, the USGS has been generating automated aftershock forecasts for earthquakes in California. These forecasts are based on statistical analyses of many aftershock sequences recorded over decades of observations. In FY 2016, the USGS began developing analytical tools and analyzing global seismicity data, working toward an automated capability for forecasting the expected size and frequency of aftershocks that occur after large earthquakes anywhere in the world. Such forecasts could be of value to a wide variety of users, including local officials, emergency responders and engineers in planning response and recovery efforts, and could be used to inform numerous other risk-mitigating activities following damaging earthquakes. In 2016, the USGS convened meetings and workshops with potential users of operational earthquake forecasts. Participants, including public and private organizations, agencies and businesses, identified decisions that could be supported by aftershock forecasts during an earthquake sequence. They also suggested ways in which the content, format, and timing of forecasts can be honed to best support situational awareness.

Computer Vision for Fast Post-Disaster Data Collection and Analysis

After an earthquake, teams of engineers and scientists must rapidly collect perishable data and time-sensitive information about the immediate effects of the event that may disappear due to recovery efforts or further damage. Data preserved post-event can enable scientific researchers to learn more about the nature of the disaster, catalogue the degree of the damage incurred, separate initial damages from aftershock damages, and help guide future research directions.

Data must also be analyzed quickly to support recovery decisions and also to identify important perishable-data gaps that need to be addressed. However, rapid analysis of post-event data is challenging. Reconnaissance teams generate a large volume of varied data in the form of photographs and videos. Current methods for analyzing these field data often involve manual systems of organization that inhibit researchers from deftly using it to guide perishable data collection.

To overcome the challenges of timely perishable data collection, a team of researchers at Purdue University, supported by the NSF, is developing new software tools to automatically organize and analyze post-disaster images in the field. The computational tools employ machine learning approaches to detect and classify types of structural damage in buildings. This system could guide post-disaster reconnaissance teams to more expediently collect and analyze high-value data that could lead to new insights into the effects of extreme events on structures.

Seismically Isolated Uni-body Structures for Residential Buildings

Damage to residential buildings in response to earthquakes can be devastating, as even moderate ground motion can cause extensive structural and architectural harm. To mitigate residential damage, a team of NSF-supported researchers from Stanford University and California State University, Sacramento have just completed a five-year research project to develop and validate new seismic design concepts for light-frame housing. The goals of the research were to develop new design and construction methods that would optimize the seismic life-cycle performance and construction costs for light-frame residential buildings and generate high-fidelity computer models to simulate the seismic response of the new designs in three-dimensions. Ultimately, the models and design methodologies were experimentally validated in tests of full buildings and building components.

The team focused on developing new design methods for uni-body frame buildings with enhanced strength coupled with low-cost isolation systems to reduce displacements between the foundation and superstructure. The light, uni-body frames increase stiffness and strength by consolidating structural and architectural components into the lateral load resisting system. Tests were performed at different scales, from single shear wall fastener tests to room assembly tests to full house shake tests. The team completed full scale testing of isolated and fixed-base, two-story uni-body residential homes at the University of California San Diego NHERI (previously the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES)) shake table facility. More information on the project and project outcomes can be found at http://nheri.ucsd.edu/projects/completed.shtml.

Rapid Response Research Data Collection from the February 2016 Southern Taiwan Earthquake

NSF supported, via its post-disaster, rapid response research (RAPID) award mechanism, researchers at the University of Washington and Purdue University to gather perishable building-response data from the M6.4 southern Taiwan earthquake that occurred near the city of Tainan, Taiwan, on February 5, 2016. This earthquake caused severe damage, partial collapse, and full collapse of low-to-midrise reinforced concrete buildings. The U.S. team traveled to Taiwan to work with Taiwanese researchers to gather detailed building-response data, including data from damaged and undamaged buildings. The team assembled a comprehensive data set that can be used by researchers and practitioners to: (1) understand the causes of building damage, (2) identify building properties that increase the probability of structural damage, (3) identify vulnerable structures in seismic areas, and (4) study the relationship of the site response and building damage. Because Taiwan has adopted seismic design methodologies like those used in the U.S., this data set also will help improve understanding of the seismic vulnerability of reinforced concrete buildings in the United States. The data set will be archived in the NSF-supported NHERI DesignSafe-CI.org website for broad use by researchers, educators, and the practicing engineering community in the U.S., Taiwan, and other countries.

Natural Hazards Center

NSF, along with other federal agencies and private industry, 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 10-13, 2016, the NHC held its Annual Natural Hazards Research and Applications Workshop in Broomfield, CO.

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

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

FEMA Performance-Based Seismic Design Guidelines Project

FEMA continued to support the development of the Performance-Based Seismic Design (PBSD) Guidelines under a contract with the Applied Technology Council (ATC). In 2016, the contract was in year three of five. Work progressed on the development of the guidelines document to provide designer guidance on the use of the FEMA P-58 Performance Assessment Products as well as several related nontechnical products for building owners, managers and other decision makers. In September 2016, ATC completed the update of FEMA's Performance Assessment Calculation Tool (PACT), Version 3.03, and posted this updated tool on their project website at https://www.atcouncil.org/53-projects/85-atc-58-project#.

2015 Edition of *NEHRP Recommended Seismic Provisions for New Buildings and Other Structures*

FEMA developed several products and resources to support the 2015 edition of the *NEHRP Recommended Provisions*. In June 2016, FEMA completed P-1050 DVD *NEHRP Recommended Seismic Provisions and Additional Resources*. This DVD is a compendium of resources associated with the 2015 *NEHRP Recommended Provisions*. The primary resource document is the two-volume 2015 *NEHRP Recommended Provisions*. The DVD also includes additional design standard and building code-related resources derived from the new edition of the *NEHRP Recommended Provisions* and other NEHRP resources. The updates to the 2015 *NEHRP Recommended Provisions* have incorporated extensive results and findings from recent research projects, problem-focused studies, and post-earthquake investigation reports conducted by various professional organizations, research institutes, universities, material industries and the NEHRP agencies.

In September 2016, FEMA released P-1051 CD, 2015 *NEHRP Recommended Seismic Provisions: Design Examples* and P-1052 CD, 2015 *NEHRP Recommended Seismic Provisions: Training Materials*. FEMA P-1051 is a collection of seismic design examples. They help to show where and how to apply the new changes in the American Society of Civil Engineers (ASCE)/Structural Engineering Institute (SEI) 7-16 standard and the 2015 *NEHRP Recommended Provisions*. FEMA P-1051 is an update of the previous edition FEMA P-751. This edition features several new chapters using design examples to illustrate the nonlinear response history analysis procedures, horizontal diaphragm analysis, soil structural interaction requirements, and structures with energy dissipation devices, which represent some major new changes in the 2015 *NEHRP Recommended Provisions* and subsequently the ASCE/SEI 7-16. The document also provides updated design examples by construction material, non-building structure and non-structural components, and includes a set of revised design flow charts.

FEMA P-1052 includes a series of lecture style presentation files. A companion of FEMA P-1051, the chapter topics are the same and were developed by the same authors. Each presentation provides an overview of relevant theoretical background, key points regarding updates contained in the 2015 *NEHRP Recommended Provisions* and ASCE/SEI 7-16, and special notes on the corresponding design examples in FEMA P-1051.

New Update Cycle for NEHRP Recommended Seismic Provisions

FEMA started a new update cycle of the *NEHRP Recommended Provisions* in FY 2016. The 2020 Provisions Update Committee (PUC) was formed in January 2016 at the Building Seismic Safety Council (BSSC) of the National Institute of Building Sciences. The new PUC consists of 22 national subject matter experts and USGS, NIST, and FEMA representatives. The PUC held a public colloquium on March 8, 2016 to inform stakeholders about the identified issues from the previous update cycle and to seek further input for issues and new topics to be explored by the new PUC. Nine issue teams were formed for this update cycle to improve seismic performance measurement, seismic force resisting systems and design coefficients, modal analysis, shear walls, nonstructural components issues, non-building structures, soil-structure interaction, design for base isolation and energy dissipation devices, and diaphragm issues. The PUC will collaborate with the Project 17 Committee to address critical issues related to seismic design value maps for the 2020 *NEHRP Recommended Provisions*, a NEHRP code resource to be used by the next edition of national design standards and model building codes.

Updating the Nation's Model Building Codes

The International Code Council continued their three-year update for the 2018 International Codes. In 2016, they conducted their Group B cycle, which was for the International Building Code, the International Existing Building Code, and the International Residential Code (IRC). The International Code Council held their Code Change Hearings from April 20 to 27 in Louisville, KY. FEMA and the Code Resource Support Committee (CRSC) (operated under contract with BSSC) submitted a total of seven seismic-related code change proposals and were successful getting recommendations for approval on six of them. The seventh proposed code change was to bring the FEMA South Napa Recovery Advisory on Masonry Chimneys into the IRC as an appendix, however, due to objections from the masonry industry and homebuilders, this change was recommended for disapproval. The CRSC provided testimony on a total of 50 other proposed code changes, either recommending approval or disapproval depending on the change. They were

successful 49 times out of 50. In two cases, the CRSC asked the proposers to modify their proposal to gain support, which they did.

Improving National Seismic Design Value Maps

FEMA provided support, via contract, for establishment of a national non-federal advisory committee of individual experts to provide technical input on the conversion of ground motion maps into model code design maps. Started in October 2015 and entitled Project 17 to reflect a continued commitment to improve the national seismic design value maps, this Committee confirmed the rules for next generation seismic design maps and associated procedures for the U.S. national consensus design standards and model building codes, as Project 97 and Project 07 did in the past. The Committee includes 14 volunteer subject matter experts and USGS, NIST, and FEMA representatives. This collaborative effort between the seismic research and engineering design communities is to investigate four primary overarching challenges identified during the planning phase: acceptable seismic risk for buildings, balancing precision and uncertainty in seismic design values, developing multi-period seismic spectral methodology and reassessing the deterministic ground motion definition and values. The Project 17 Committee participated in a public discussion of its scope of effort and focused areas at a BSSC PUC colloquium on March 8, 2016.

National Seismic Hazard Assessment Update

USGS experts worked with FEMA, NIST, and the building design community to adopt new seismic hazard estimates into engineering design maps and the 2018 International Building and Residential Codes. The USGS released a set of new computer codes used to conduct seismic hazard assessments; the release included the 2008 and 2014 updates to the USGS National Seismic Hazard Maps (NSHM), the 1997 Hawaii and 2007 Alaska seismic hazard models, an offline hazard de-aggregation calculator, and an early version of a Unified Hazard Tool. The USGS also prepared supplementary maps for the 2015 *NEHRP Recommended Provisions* for a DVD release.

The USGS also collaborated with FEMA and the BSSC to define plans for Project 17, which involves a set of directed research activities to improve procedures used for developing design maps for building codes from the NSHM. The USGS also communicated with the Pacific Earthquake Engineering Research Center (PEER) on plans to adopt a suite of new ground motion attenuation relations under development for the central and eastern U.S. (NGA-East) into NSHM. Ground motion attenuation with distance from an epicenter is an important factor in estimating ground shaking hazard. The USGS staff also continued collaborations with the Southern California Earthquake Center (SCEC) on development of ground motion design maps based on earthquake simulations from the SCEC CyberShake project.

Support for Engineering Practitioners

NIST continued to support practicing structural engineers by providing timely design guidelines for use in practice and education. NIST published three technical briefs that are updates to TechBrief No. 1, *Seismic Design of Reinforced Concrete Special Moment Frames: A Guide for Practicing Engineers Second Edition*, NIST GCR 16-917-40; TechBrief No. 2, *Seismic Design of Steel Special Moment Frames: A Guide for Practicing Engineers Second Edition*, NIST GCR 16-917-41; and TechBrief No. 3, *Seismic Design of Cast-in-Place Concrete Diaphragms, Chords, and Collectors: A Guide for Practicing Engineers Second Edition*,

NIST GCR 16-917-42. NIST also published a new TechBrief No. 12, *Seismic Design of Cold-Formed Steel Lateral Load-Resisting Systems: A Guide for Practicing Engineers*, NIST GCR 16-917-38.

NIST continued its research into improved Performance Based Seismic Engineering approaches with ongoing work involving ASCE 41, *Seismic Evaluation and Retrofit of Existing Buildings.* Work on a study involving buckling restrained braces was concluded. A preliminary study of reinforced concrete special moment frames and how ASCE 41 characterizes them was begun to ascertain how well ASCE 41 predicts the performance of buildings designed using prescriptive methods found in ASCE 7, *Minimum Design Loads for Buildings and Other Structures*. NIST continued its involvement in technical committees responsible for ASCE 7 and ASCE 41 as well as committees developing material specific design standards. The American Iron and Steel Institute (AISI) Committee on Framing Standards Lateral Design published ANSI/AISI S100-16, *North American Specification for the Design of Cold-Formed Steel Structural Members*, the American Institute of Steel Construction (AISC) published ANSI/AISC 341-16, *Seismic Provisions for Structural Steel Buildings*, and the American Concrete Institute (ACI) published ACI 318, *Building Code Requirements for Structural Concrete*.

3.3 Goal C: Improve the Earthquake Resilience of Communities Nationwide

Through activities supported under Goal C, NEHRP agencies work to apply research results developed under Goal A and risk-reduction methodologies developed under Goal B to practical measures that will increase public safety and reduce losses in future earthquakes. Work under this goal includes the monitoring and reporting of seismic activity worldwide. Goal C directly supports the congressionally-defined NEHRP program activity, "promote the adoption of earthquake hazards reduction measures by Federal, State, and local governments, national standards and model code organizations, architects and engineers, building owners, and others with a role in planning and constructing buildings, structures, and lifelines." 42 U.S.C. § 7704(a)(2)(B).

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

Community Resilience Considerations Concerning Lifelines

NIST published a study of societal needs concerning lifelines and their critical role in community disaster recovery. The report *Critical Assessment of Lifeline System Performance: Understanding Societal Needs in Disaster Recovery*, NIST GCR 16-917-39, provides a critical assessment of lifeline system performance across hazard events with an emphasis on improved performance during an event and shorter recovery times. This report was an effort by the Earthquake Engineering and the Community Resilience Groups at NIST.

Earthquake Response Exercises

In June 2016, FEMA sponsored Cascadia Rising 2016, a four-day, large scale exercise to test response and recovery capabilities in the wake of a M9.0 Cascadia Subduction Zone earthquake and tsunami. The exercise involved more than 20,000 emergency managers in Idaho, Oregon and Washington along with local, state, tribal and federal partners, military commands, private sector and non-governmental organizations. Emergency management centers at local, state, tribal and federal levels in coordination with military commands, private sector and non-governmental organizations in Washington, Oregon, and Idaho, activated to coordinate simulated field response operations. The Cascadia Rising 2016 exercise was to test plans and procedures through a M9.0 earthquake and follow-on tsunami with expectations to improve catastrophic disaster operational readiness across the whole community. FEMA Earthquake Program staff acted as Subject Matter Experts and provided input throughout the exercise.

The USGS provided aftershock forecasts and ShakeMaps and PAGER information sheets for the scenario mainshock and seven aftershocks. During the exercise, the USGS performed a TweetChat, led field trips, participated in the California Clearing House, and embedded staff at USNORTHCOM and the Regional Response Coordination and National Response Coordination Centers. These staff provided technical and scientific information and context to the exercise participants.

ShakeOut Earthquake Drills

NEHRP agencies again supported ShakeOut, the world's largest earthquake preparedness drill for governments, schools, businesses, other organizations, and homes. In FY 2016, almost 44 million people participated in ShakeOut activities worldwide, of which over 21.2 million were from the U.S., including participants from the District of Columbia and 50 U.S. States and Territories. Texas was added as a separate site. NEHRP provides financial support to SCEC to provide personalized state/territory and regional ShakeOut websites, press releases, multimedia products, ShakeOut planning and messaging templates, drill guides, registration support, and technical planning assistance. All ShakeOut exercises benefit from the direct involvement of staff from the NEHRP agencies.

Social and traditional media coverage of ShakeOut increases each year. In FY 2016, ShakeOut trended on Twitter in 33 major cities worldwide. ShakeOut was highlighted in 400 online articles, 650 TV reports, and 140 radio reports. For the fourth year, ShakeOut was featured in the monologue of Jimmy Kimmel Live! the night that it took place. The day after ShakeOut, the Rachel Maddow Show included a report about the drill in a story about Oklahoma earthquakes.

Earthquake Early Warning

EEW is the capability to quickly and automatically identify and characterize an earthquake after it begins, calculate the intensity of ground shaking that is expected to result, and deliver warnings within seconds to populations and critical systems that may experience damaging shaking. Recent federal, state, and private investments have resulted in a prototype EEW system called ShakeAlert, which has been sending live alerts to selected test users since January of 2012. As described in the published 2014 technical implementation plan, the vision of the USGS ShakeAlert project is to build and operate a reliable, public EEW system for the West Coast of the United States.

The demonstration EEW system in California has more than 75 test users receiving alerts and has successfully sent test alerts for several damaging earthquakes.

In FY 2016, Congress provided $8.2M to the USGS for earthquake early warning. These funds were used to accelerate the ShakeAlert development effort, including the expansion of seismic network coverage that is needed to ensure accurate earthquake alerts and the integration of ground motion data in real-time from GPS sites. To support partner activities in earthquake early warning, approximately $4M was provided in FY 2016 to academic institutions through cooperative agreements. These funds were provided to the California Institute of Technology, the University of California, Berkeley, the University of Washington, Central Washington University, the University of Nevada at Reno, and the University of Oregon to support transitioning the ShakeAlert EEW toward a production stage. USGS additionally spent $1.5M to purchase new sensor equipment.

On February 2, 2016, the Executive Office of the President held a Summit on Earthquake Resilience that included a focus on earthquake early warning. The release of EO 13717 -- *Establishing a Federal Earthquake Risk Mitigation Standard* was announced at the meeting. In addition, the Secretary of the Department of the Interior announced the release of the first production prototype of the USGS ShakeAlert system, and the Directors of the USGS and NIST and the Director of OSTP, as well as six members of Congress, made comments in support of the ShakeAlert system.

GAO Report on Seismic Safety of Federal Buildings

On September 22, 2016, the U.S. Government Accountability Office issued a report on "Earthquakes: Additional Actions Needed to Identify and Mitigate Risks to Federal Buildings and Implement an Early Warning System." The report focused on the seismic safety of existing federally owned and leased buildings (primarily by GSA and DOD) and referenced several FEMA Building Science technical design guidance products.

Executive Order 13717: *Establishing a Federal Earthquake Risk Management Standard*

On February 2, 2016, the White House issued EO 13717 that superseded EO 12699 and EO 12941 on Seismic Safety. EO 13717 directed the Federal Government to continue to take proactive steps to enhance the resilience of buildings that are owned, leased, financed, or regulated by the Federal Government. NIST, on behalf of NEHRP, supported the Executive Office of the President by leading the development of implementation guidelines for the EO, coordinating interagency input and clearances, and posting the final implementation guidelines[5] to the NEHRP website so they are readily available to all interested parties.

[5] See NIST Technical Note 1922, ICSSC Recommended Practice (RP) 9 – Implementation Guidelines for Executive Order 13717: Establishing a Federal Earthquake Risk Management Standard, dated January 2017, at https://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.1922.pdf

3.4 NEHRP Statutory Activity: Program Leadership

There are several statutory NEHRP program management, coordination, and oversight functions. 42 U.S.C. §§ 7704(a)(3) & (5). In FY 2016, the ACEHR[6] met face-to-face one time. The principal-level Interagency Coordinating Committee[7] met face-to-face one time in FY 2016. The working-level Program Coordination Working Group (PCWG), established by the NEHRP Secretariat, met face-to-face four times and held three teleconferences.

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 2016. The full text of the recommendations and corresponding NEHRP agency response are available on the NEHRP website.[8]

NEHRP Secretariat Operations

The NIST NEHRP Secretariat continued to provide program coordination. The office organized and conducted the ACEHR and PCWG meetings and maintained the NEHRP website (http://www.nehrp.gov/). This website provides information on NEHRP management efforts and resources, as well as links to the four program agencies where further information on earthquake research results, current seismic activity, seismic hazard and risk, and earthquake mitigation practices can be found.

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

Public Law 108–360 requires that NEHRP "develop, operate, and maintain" certain facilities essential to the NEHRP mission. 42 U.S.C. § 7704(a)(2)(D). These facilities are the ANSS, maintained and operated by USGS; the GSN, maintained and operated cooperatively by USGS and NSF; and NHERI, maintained and operated by NSF. Below are reports on the FY 2016 activities and status of these facilities.

Advanced National Seismic System (ANSS)

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

[6] ACEHR is composed of 11 to 17 members selected on the basis of established records of distinguished service in their professional community and their knowledge of issues affecting NEHRP, who are not federal employees and who are appointed to three-year staggered terms of service. The Chairperson of the USGS Scientific Earthquake Studies Advisory Committee (SESAC) serves as a non-voting *ex-officio* member of ACEHR.

[7] The Interagency Coordinating Committee is composed of the Directors/Administrators of the four NEHRP agencies as well as the Directors of OMB and OSTP.

[8] See http://nehrp.gov/pdf/2016ACEHRReportInterim.pdf, and http://nehrp.gov/pdf/2016ACEHRReportResponseNIST.pdf.

National Earthquake Information Center (NEIC), 11 partner-operated regional networks, and the National Strong Motion Project (NSMP) for monitoring earthquake shaking in the free field and in structures. Thanks to substantial improvements to station coverage and methods for rapid analysis, the ANSS now typically reports on domestic earthquakes large enough to be felt by humans within minutes of their occurrence.

The number of ANSS-standard stations increased from 2,922 in FY 2015 to 2,991 in FY 2016, including 156 instrumented structures. As part of the ANSS, the USGS and 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 United States 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. To support core partner activities in earthquake monitoring, in FY 2016, approximately $6.6M was provided through established cooperative agreements with academic and other non-USGS institutions for operation of regional seismic and geodetic networks and of structural and geotechnical arrays. It should also be noted that the NSMP's recent improvements to the Anchorage Strong Motion Network resulted in excellent data being recorded from the January 24, 2016 M7.1 Iniskin earthquake in south-central Alaska.

Global Seismographic Network

The GSN consists of 150 stations worldwide. It is jointly supported by the USGS and the NSF, and is operated by the USGS in partnership with the Incorporated Research Institutions for Seismology (IRIS). The GSN provides high-quality seismic data to support earthquake alerts, tsunami warnings, hazard assessments, national security (through 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 or larger) 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 2016, the USGS and IRIS continued to operate the GSN at a high level of data recovery, real-time telemetry performance, and high cost efficiency. The USGS continued to lead a multi-agency effort to develop and procure new borehole sensors, as part of ongoing efforts to maintain and improve the GSN. The GSN data quality has been high in recent years, due to the upgrades of data loggers and the development of software to automatically assess GSN data quality, and to identify and diagnose performance issues. The USGS developed and implemented new software to automatically assess the quality of GSN data, allowing staff at the USGS Albuquerque Seismological Laboratory to identify, diagnose, and fix station performance problems quickly. This has resulted in unprecedented data quality and availability for the USGS-operated stations of the network.

Natural Hazards Engineering Research Infrastructure (NHERI)

The 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 that can contribute knowledge and innovation to prevent natural hazards from becoming societal disasters. This knowledge base could potentially transform how future civil infrastructure will be designed and how existing civil infrastructure might be rehabilitated. Civil infrastructure designed to be multi-hazard resilient will contribute toward broader societal goals, i.e., protect people and property, maintain continuity in essential operations and services, and recover rapidly from a natural hazard event. Information on NHERI and the 11 awards is available at https://www.designsafe-ci.org/.

Under program solicitation NSF 15-598, NSF competed the remaining three NHERI awards. The following awards were made in FY 2016 for NHERI:

- Post-Disaster, Rapid Response Research (RAPID) Facility at the University of Washington
- Computational Modeling and Simulation Center (SimCenter) at the University of California-Berkeley
- Network Coordination Office at Purdue University

The NHERI RAPID facility will provide capabilities to conduct quick response research with a variety of cutting-edge 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 will continue to acquire new, major instrumentation before beginning field deployment in 2018. The NHERI 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. The tools supplied by the SimCenter will be available at https://www.designsafe-ci.org/. The Network Coordination Office 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, including a Research Experiences for Undergraduates (REU) program and a Summer Institute for graduate students and early career faculty.

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, addressing important challenges in multi-hazard mitigation for constructed civil infrastructure.

Section 4 - Activities to Promote Preparedness, Hazard Mitigation Efforts, and Resilience

4.1 The FEMA Earthquake State Assistance Program

Alaska
Alaska, in partnership with the Federal Alliance for Safe Homes (FLASH), updated the Individual & Family Preparedness Guide which provides a step-by-step approach to disaster preparedness by walking the reader through how to get informed about local emergency plans, how to identify hazards that affect their local area, and how to develop and maintain an emergency communications plan and disaster supply kit. A total of 3,000 publications were printed, and FLASH developed an electronic version of the guide for use on the internet.

The 2015 Alaska's Next Big Earthquake Workshop was held in Fairbanks. The Western States Seismic Policy Council (WSSPC) helped sponsor the event. The workshop was conceived to bring together all parties with earthquake-related concerns and to lay the foundation for relationships that can educate Alaskans with the combined assets of all partners, with a goal of creating a long-term working group to guide these efforts.

Arkansas
The Arkansas Department of Emergency Management, in partnership with the Central United States Earthquake Consortium (CUSEC), SCEC, IRIS, and USGS, led an effort to implement the "Quake Catcher Network" (QCN) program. QCN uses low-cost earthquake sensors to teach citizens about earthquake monitoring, seismology, and geology. The program included creating an installation manual and instructional videos and installing 20 QCN devices within the state of Arkansas.

Arkansas, in partnership with FLASH, promoted the ShakeOut drill through the development and deployment of 19 "Drop, Cover and Hold On" billboards.

Arizona
On behalf of the state of Arizona Yuma Emergency Management Department, FLASH distributed 11,000 mobile home mitigation flyers to 38 mobile home parks throughout Yuma, AZ. Yuma Emergency Management and the local CERT team distributed an additional 25,000 flyers through various local outreach events. The flyers promoted seismic preparedness and nonstructural mitigation and provided resources for additional information.

California
In FY 2016, the state hosted the National Earthquake Conference of 2016 (see 4.2 below), conducted one of the nation's largest ShakeOut exercises in history and hosted a *QuakeSmart* Business Preparedness Summit in partnership with FLASH.

Over 10.5 million state residents participated in the October 19, 2016 ShakeOut earthquake drill. FEMA representatives along with USGS, the California Office of Emergency Services, the California Earthquake Authority, the Insurance Information Institute, and several state organizations

participated in The Great California ShakeOut at the Googleplex, Google's headquarters in Mountain View, CA.

SCEC and the Earthquake Country Alliance (ECA) participated in the National Science Teachers Association conference held in Los Angeles, promoting ShakeOut participation and the SCEC "Quake Heroes" program to science teachers from across the country.

ECA supported the San Francisco EPIcenter conference and a partners' meeting for the HayWired Scenario for a major earthquake on the Hayward fault. A regional workshop was held at the USGS offices in Menlo Park which focused on earthquake science, with Dr. David Schwartz and others providing updates on Bay Area hazards.

ECA presented Together We Prepare! Personal & Community Emergency Preparedness, an earthquake preparedness workshop at the Los Angeles Abilities Expo 2016. Presenters were from the Earthquake Country Alliance, California Office of Emergency Services, County of Los Angeles, City of Los Angeles, and American Red Cross. ECA SoCal also supported the "Beat the Quake" educational contest held on April 28th at Cal State University Northridge. More than 200 students and staff participated, and the activity won a FEMA Individual and Community Preparedness Award.

For ECA's Redwood Coast Tsunami Workgroup, SCEC printed an English-language update of Living on Shaky Ground, a magazine-style publication covering earthquake and tsunami hazards of the North Coast of California, as well as the Seven Steps of Earthquake Safety. In addition, a Spanish-language update of the booklet was printed for the first time.

Colorado

Colorado Geological Survey (CGS) and FUGRO Consulting placed two trenches across the "new" northern extension of the Cheraw fault in SE Colorado to study the earthquake history of the fault, with technical support from USGS. CGS also installed a seismometer east of Greeley, near Briggsdale, CO. Additional installations are planned, and all are part of the CGS earthquake program.

Colorado continued the Colorado Earthquake Hazard Mitigation Council, a multi-disciplinary organization that is interested in developing a better understanding of earthquake hazards in Colorado. CGS promotes public education on earthquake hazards through social media, blog posts, and their website.

The Colorado Resiliency and Recovery Office created a statewide resiliency plan (all hazards) and a 2016 resiliency framework. The framework represents Colorado's long-term commitment to making resiliency to all hazards a reality in the state. The Colorado Department of Local Affairs (DOLA) created a new all hazards planning guide and website that includes earthquakes. The guide, "Planning for Hazards Land Use Solutions for Colorado", provides detailed, Colorado-specific information about how to assess a community's risk of hazards and how to implement several land use planning tools and strategies for reducing a community's risk. Following rollout of the guide and website, DOLA has hosted numerous webinars and given numerous presentations about Colorado hazards and using the guide to improve community resiliency.

Connecticut

The Connecticut Division of Emergency Management and Homeland Security, with support from the Northeast States Emergency Consortium (NESEC), pursued use of FEMA HAZUS-MH software.

Hawaii
Over 80 people attended the WSSPC-sponsored *Building a Resilient Hawaii* workshop in Honolulu in February 2016. The workshop addressed Hawaii's hazards and how projects in one area can be leveraged for mitigation; emerging technologies and projects such as earthquake early warning and tsunami "Play Books"; outreach activities; and educational resources.

Illinois
Illinois, in partnership with FLASH, promoted the ShakeOut drill through the development and deployment of 24 "Drop, Cover and Hold On" billboards.

Indiana
Indiana, in partnership with the Central United States Earthquake Consortium (CUSEC), delivered earthquake education to more than 550 students and teachers in six outreach events as part of the Indiana Quake Cottage program. Quake Cottage is a mobile earthquake simulator that teaches citizens about earthquake hazards and how to mitigate against potential damage.

Kentucky
Kentucky continued to develop the Kentucky Community Hazard Assessment and Mitigation Planning System (CHAMPS) tool, which provides an information system for hazard assessment and mitigation planning. CHAMPS allows counties to input specific information about their community and resources, as well as conduct assessments to understand its risks and develop mitigation plans to address those risks. The system enables tracking of mitigation plans and projects, which further fosters community resiliency. It also allows Kentucky Emergency Management a way to streamline many different sources of information into one system, reducing administrative burdens.

Maine
Maine, with support from NESEC, continued its three-year HAZUS Modeling and Analysis project and NESEC prepared HAZUS-MH Earthquake Analysis for five counties. NESEC analyzed adoption of the Maine Uniform Building and Energy Code in relation to earthquake risk and developed web page concept for code adoption public awareness.

Missouri
The Missouri SAVE Coalition hosted a regional building assessment exercise in St. Louis with more than 200 participants from across the Midwest. This exercise included the first test of a new NEHRP-funded phone app to collect assessment data. New state legislation introduced in FY 2016 now allows Missouri's SAVE Coalition to deploy to other states to assist in response. Missouri participated in a National Emergency Management Association-funded Mission Ready Package Workshop as part of the development of the Emergency Management Assistance Compact process.

Missouri's Rapid Visual Screening (RVS) Program expanded in FY 2016, using FEMA's National Earthquake Technical Assistance Program training for volunteers and NEHRP funds for administrative costs and volunteer travel. The program completed assessments and reports for four schools in high-seismic areas, as well as provided some seismic restraint fasteners as part of follow-up.

Missouri's ShakeOut had more than 520,000 registered participants. Missouri also hosted the second annual "Rock, Fossil, Quake" earthquake outreach event at the St. Louis Science Center. The event was developed by the Science Center, CUSEC, USGS, and others as a linked event to the Great ShakeOut and National Preparedness Month. Approximately 5000 people attended the event.

New Hampshire
NESEC assisted New Hampshire in analyzing earthquake risk to 322 Critical and Essential Facilities using FEMA's HAZUS-MH, with a focus on waste water treatment plants. NESEC also conducted a Department of Homeland Security Integrated Rapid Visual Screening earthquake and all-hazards analysis of the NH Incident Planning and Operations Center. NESEC provided the Central New Hampshire Regional Planning Commission with a HAZUS-MH earthquake map layer and technical assistance as to how best to incorporate the map layers into 19 local hazard mitigation plans.

Nevada
Nevada continued the Clark County Unreinforced Masonry (URM) Verification project. This project allowed the Clark County Department of Building and Fire Prevention to partner with the NEHRP funding through the Earthquake Engineering Research Institute (EERI) to go out and do a verification of the initial list of URM buildings in unincorporated Clark County. The project was done by manual process. This information is available to both the state as well as Clark County in the updates of their hazard mitigation plans. The state of Nevada is working to do a URM verification across the state to provide better awareness of exactly where these at-risk buildings are in the event of disasters. There were 651 commercial URM structures and 4029 residential structures identified from the initial list for the Clark County area. The verification process resulted in determination of 84 Commercial and 155 residential URM structures in unincorporated Clark County.

Nevada developed the Clark County URM App through EERI to help automate the URM verification process as Clark County Building continues the process of URM verification within incorporated Clark County. The App is being utilized for the additional URM verification process for the current Clark County Hazard Mitigation plan update. The App is also available for other areas in the state to utilize in their URM verification work.

With support from WSSPC, Nevada placed 10 digital billboards and four static billboards in the Las Vegas Valley to publicize the "Drop, Cover, and Hold On" earthquake message during the month of the ShakeOut drill. The campaign resulted in almost 29 million impressions during the four-week run.

Oregon
The Oregon Office of Emergency Management (OEM) conducted the Island Mapping Project, with support from the Cascadia Region Earthquake Workgroup (CREW), which included six workshops held along the coast to assist emergency management agencies with updated mapping and analytics relating to population density and seismic vulnerability during a Cascadia Subduction Zone earthquake and tsunami in order to identify populations that will be isolated due to infrastructure damage.

Oregon also participated in the June 2016 Cascadia Rising Earthquake Exercise (see 4.3 below), including the Functional Exercise and the Public Messaging Campaign.

South Carolina
South Carolina Emergency Management Division (SCEMD) hosted the Earthquake Recovery Exercise in March 2016. CUSEC delivered a presentation on the need for post-earthquake safety assessments, which are required following a large-scale disaster, to determine safe occupancy of homes and businesses.

Utah
The Utah Seismic Safety Commission held its biennial meeting with the Nevada Seismic Safety Council in Reno and the Utah Chapter of EERI conducted a Utah Earthquake Resiliency Workshop with 125 attending.

Utah co-sponsored the unveiling of Salt Lake City's "Fix The Bricks" URM home retrofit initiative and completed the revisions to the Utah Guide for Seismic Improvement of URM Dwellings for the "Fix The Bricks" initiative.

Utah finished the data collection for the Rapid Visual Screening of most of the K-12 schools in the state and they conducted ATC-20 training for university and college facilities personnel with 110 attending.

Vermont
Vermont, with support from NESEC, analyzed earthquake risk to 26 Critical and Essential Facilities using FEMA's HAZUS-MH and Rapid Observation of Vulnerability and Estimation of Risk (ROVER) Software. NESEC prepared a HAZUS-MH earthquake analysis hazard layer for one Vermont County for incorporation into a multi-hazard county risk map.

Washington
In partnership with EERI and regional engineering society volunteers, Washington completed seismic safety assessments at 15 schools in Thurston County. The results will support development of mitigation strategies to retrofit or replace the buildings with the highest risk, and help districts prioritize resources. Washington conducted a media day in Yelm to highlight the effort and secured media coverage in the Seattle Times, NW Public Radio and Northwest network news.

The state also participated in the June 2016 Cascadia Rising Earthquake Exercise, including the Functional Exercise and the Public Messaging Campaign.

Wyoming
As a NEHRP state support project, Wyoming developed Earthquake Playing Cards, which are decks of playing cards with earthquake preparedness messaging on the face of each card within the deck. Each card face has a different preparedness message or Wyoming-specific earthquake hazard information, and because the cards are a game, the preparedness message will be seen multiple times over a long period of time, rather than received as a flier, read once and thrown away. The cards are being shared with the public throughout Wyoming through multiple avenues.

The visual assessment of critical infrastructure within the Star Valley Fault was completed. The goal of the assessment was to pursue future mitigation actions to minimize the impact of an earthquake on critical infrastructure, particularly hospitals, schools, previously-identified shelter locations, and locations housing ambulance, fire and law enforcement response vehicles.

Wyoming purchased water heater straps for distribution and use at homes located in western parts of the state, where the seismic risk is greatest. The straps are provided to local emergency managers who work in conjunction with local building supply companies at home and garden shows or other publicly-advertised venues. An installation demonstration was provided, and the public was encouraged to install the straps on their water heater.

For information on all significant FEMA state assistance activities for FY 2016, please visit https://www.fema.gov/nehrp-grant-program.

4.2 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 2016, the USGS provided substantial support to state institutions, private companies and non-governmental organizations for earthquake monitoring and applied research. This external research activity allows the USGS to efficiently accomplish its goals in assessing earthquake hazards, the physics of earthquakes, earthquake occurrence, and earthquake safety policy. Partner organizations assist the USGS by providing earth science data and assessments essential for land-use planning, engineering design, and emergency preparedness decisions

The following table lists the external grants by award number that USGS provided in FY 2016 to organizations in 28 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.

Award No.	Principal Investigator(s)	Project Title	Institution
G14AP00119	Kevin Franke	Probabilistic Liquefaction Potential and Lateral Spread Hazard Maps for Utah County, Utah: Collaborative Research with Brigham Young University and Oregon State University ($43,197; August 2014 through January 2016)	Brigham Young University
G15AC00332	John Vidale & Paul Bodin	Implementation and Development of US West Coast ShakeAlert: Collaborative Research with UCB, CalTech, UW & UO (EEW1)($742,727; August 2015 through July 2017)	University of Washington
G15AP00034	H. Gary Greene	Investigation of Recent Deformation Along the Queen Charlotte-Fairweather Fault System in Canada and Alaska, USA ($96,034; January 2015 through December 2016)	Sitka Sound Science Center
G15AP00048	Anne Egger	Earthquake Hazard Assessment of the Winter Rim Fault System, Eastern Oregon ($61,851; June 2015 through September 2016)	Central Washington University
G15AP00051	Jeffrey Freymueller	Geodetic Contributions to the Alaska Hazard Maps: Collaborative Research with the University of Alaska Fairbanks and Purdue University ($80,644; April 2015 through December 2016)	University of Alaska Fairbanks

Award No.	Principal Investigator(s)	Project Title	Institution
G15AP00052	Carl Tape	Characterization of Crustal Faulting in Southern Alaska using Moment Tensors Derived from the Full Seismic Waveforms ($91,916; April 2015 through March 2017)	University of Alaska Fairbanks
G15AP00053	Natalia Ruppert & Jeffrey Freymueller	Characterization of Earthquake Sources in Near-Real Time along the Alaska-Aleutian Subduction Zone using Continuous Seismic and High Rate GPS Data ($75,607; April 2015 through March 2016)	University of Alaska Fairbanks
G15AP00080	Mark Person & Peter Mozley	The Hydrologic Connection Between Basal Reservoir Injection, Micro/Mesoscale Crystalline Basement Fault Zones, and Induced Seismicity: Collaborative Research with Utah State University and New Mexico Tech ($79,081; June 2015 through May 2017)	New Mexico Tech
G15AP00114	Paul Jewell	Characterization of Segmentation and Long-Term Slip Rates of Wasatch Front Fault Systems, Utah ($67,903; August 2015 through February 2017)	University of Utah
G15AP00117	Michael Hylland	Paleoseismic Investigation of the Taylorsville Fault, West Valley Fault Zone, Salt Lake County, Utah ($45,730; August 2015 through January 2017)	Utah Geological Survey
G16AC00135	Craig Glennie	Imaging near-fault earthquake deformation with integrated SAR, LiDAR, and Optical Measurements ($146,859; June 2016 through December 2019)	University of Houston
G16AC00247	Heather DeShon & Beatrice Magnani	Imaging Faults in Induced Earthquake Zones using Earthquake and Controlled Source Data - North Texas and Northern Oklahoma ($60,479; July 2016 through December 2016)	Southern Methodist University
G16AC00348	Richard Allen & Margaret Hellweg	Implementation and Development of US West Coast ShakeAlert: Collaborative Research with University of California at Berkeley, California Institute of Technology, University of Washington, and University of Oregon (EEW7) PHASE V ($1,291,983; August 2016 through August 2017)	University of California Berkeley
G16AC00354	Douglas Toomey	Implementation and Development of US West Coast ShakeAlert 2016: Collaborative Research with Univ. of California at Berkeley, California Institute of Technology, Univ. of Washington, and Univ. of Oregon (EEW2) PHASE V ($237,150; August 2106 through August 2017)	University of Oregon
G16AC00355	Thomas Heaton & Egill Hauksson	Implementation and Development of US West Coast ShakeAlert 2016: Collaborative Research with Univ. of California at Berkeley, California Institute of Technology, Univ. of Washington, and Univ. of Oregon (EEW1) PHASE V ($975,365; August 2016 through August 2017)	California Institute of Technology
G16AC00356	John Vidale & Paul Bodin	Implementation and Development of US West Coast ShakeAlert: Collaborative Research with Univ. of California at Berkeley, California Institute of Technology, Univ. of Washington, and Univ. of Oregon (EEW3) PHASE V ($571,901; August 2016 through August 2017)	University of Washington
G16AC00357	Timothy Melbourne	Incorporating Real-time GNSS into ShakeAlert: Collaborative with Central Washington University and UNAVCO Inc. (EEW6) PHASE V ($491,777; August 2016 through August 2017)	Central Washington University

Award No.	Principal Investigator(s)	Project Title	Institution
G16AC00358	Graham Kent & Ken Smith	Earthquake Early Warning in Eastern California (EEW4) PHASE V ($169,908; August 2016 through August 2017)	University of Nevada, Reno
G16AP00003	Ronald Andrus	Reducing Uncertainty of Liquefaction Hazard Assessments in Aged Soil Deposits ($39,945; December 2015 through November 2016)	Clemson University
G16AP00004	Yuri Fialko	Models of Earthquake Recurrence in the Imperial Fault Constrained by Surface Deformation Data and Laboratory-Derived Constitutive Laws ($87,886; January 2016 through December 2016)	University of California San Diego
G16AP00005	Jonathan Stewart	Towards the Development of Community Consensus on Site Amplification in Central and Eastern North America ($48,562; December 2015 through June 2017)	University of California Los Angeles
G16AP00006	Henry Burton & Jonathan Stewart	Stochastic Characterization of Aftershock Building Collapse Risk ($74,722; January 2016 through December 2016)	University of California Los Angeles
G16AP00007	Roland Burgmann & Robert Nadeau	Interseismic Coupling of the North San Francisco Bay Faults from InSAR, GPS, and Seismic Data: Collaborative Research with UC Berkeley and USGS Menlo Park ($169,474; December 2015 through May 2018)	University of California Berkeley
G16AP00008	Seth Wittke	Preliminary Investigation and Surficial Mapping of the Faults North and South of Blacktail Butte, Teton County, Wyoming ($8295; January 2016 through December 2016)	Wyoming State Geological Survey
G16AP00009	James Turner, Cooper Brossy & Daniel O'Connell	Geophysical Site Characterization of Bay Area Seismic Monitoring Stations: Vs-Dept Profiling, NEHRP Site Classifications, and Linear Amplification Functions ($59,304; January 2016 through December 2016)	Fugro Consultants, Inc.
G16AP00010	Anne Sheehan & Shemin Ge	Feasibility of Controlling Induced Earthquakes: Seismicity Investigation Coupled with Hydrologic Modeling of an Actively Mitigated Class II Disposal Well and Data Collection at New High Rate Wells, Weld County, Colorado ($79,974; January 2016 through December 2017)	University of Colorado Boulder
G16AP00012	Robert McCaffrey	Slip and Stress Rates on Crustal Faults in the Puget-Williamette Urban Corridor: Collaborative Research with Portland State University and Massachusetts Institute of Technology ($40,103; January 2016 through December 2016)	Portland State University
G16AP00013	Andrew Newman	NEIC Implementation of Real-Time Earth Energy and Rupture Duration ($58,939; January 2016 through June 2017)	Georgia Institute of Technology
G16AP00014	Laurie Baise	Validation of a Geospatial Liquefaction Model for Noncoastal Regions Including Nepal ($75,949; March 2016 through September 2017)	Tufts University
G16AP00015	Thomas Rockwell & Monte Murback	Mid to Late Holocene Rupture History of the Rose Canyon Fault in San Diego, CA ($84,608; January 2016 through January 2018)	San Diego State University
G16AP00017	Felix Waldhauser & David Schaff	Near-Real-Time Monitoring and Analysis of Repeating Earthquakes in North California ($83,065; January 2016 through December 2016)	Columbia University
G16AP00021	Miaki Ishii	Digitization of Harvard-Adam Dziewonski Analog Seismograms from 1933 to 1953 for Improved Seismicity Constraints in the Northeastern United States ($18,933; January 2016 through December 2016)	Harvard University

Award No.	Principal Investigator(s)	Project Title	Institution
G16AP00022	Tandis Bidgoli	Mapping Subsurface Lineaments, Present-Day Stresses, and Brine Disposal Data in Southern Kansas: A New Approach for Identifying Areas at Risk for Injection-Induced Seismicity ($75,091; May 2016 through May 2017)	University of Kansas
G16AP00023	Elizabeth Hearn	Kinematic and Dynamic Models of the Southern California Lithosphere: Applications to Estimating Crust Stresses and Stressing Rates ($28,600; January 2016 through December 2016)	Elizabeth Hearn
G16AP00024	David Oglesby	The Dynamics of Earthquake and Tsunamis along the Alaskan-Aleutian Subduction Zone: Collaborative Research with the University of California Riverside and the US Geological Survey ($55,218; January 2016 through June 2017)	University of California Riverside
G16AP00025	Steven Jaume & Norman Levine	Development of a Community Velocity Model for the Charleston, South Carolina Region ($96,145; January 2016 through December 2017)	College of Charleston
G16AP00027	Chris Marone	Ultrasonic Imaging of Laboratory Faults to Illuminate the Micro-Mechanical Origins of Rate and State friction: Collaborative Research with Princeton University and Pennsylvania State University ($56,767; February 2016 through January 2017)	Pennsylvania State University
G16AP00028	Allan Rubin	Ultrasonic Imaging of Laboratory Faults to Illuminate the Micro-Mechanical Origins of Rate and State Friction: Collaborative Research with Princeton University and Pennsylvania State University ($56,765; February 2016 through January 2017)	Princeton University
G16AP00030	Jeffrey McGuire	Beyond the Corner Frequency: Connecting Dynamic Source Models to Seismic Observations ($79,902; February 2016 through January 2017	Woods Hole Oceanographic Institution
G16AP00034	Gareth Funning	Mapping the Extents of Creep on the Faults of the Northern San Francisco Bay Area using Repeating Earthquakes ($44,307; March 2016 -- February 2017)	University of California Riverside
G16AP00035	Peter Shearer	Analysis of Nevada Seismicity Using Improved Locations, Focal Mechanisms and Stress Drops: Collaborative Research between UC San Diego and University of Nevada, Reno ($54,430; March 2016 -- August 2017)	University of California San Diego
G16AP00036	Ken Smith & Rachel Abercrombie	Analysis of Nevada Seismicity Using Improved Locations, Focal Mechanisms and Stress Drops: Collaborative Research between UC San Diego and University of Nevada, Reno ($41,038; March 2016 through August 2017)	University of Nevada Reno
G16AP00059	Zheng-Kang Shen	Updating Western US Crustal Motion Map ($57,687; March 2016 through February 2017)	University of California Los Angeles
G16AP00060	Seth Dee & Alan Ramelli	Pilot Paleoseismic Investigation of Faults in the North Valleys, Reno, Nevada ($59,375; March 2016 through June 2018)	University of Nevada Reno
G16AP00094	Lorraine Hwang, Donna Eberhart-Phillips, Louise Kellogg & M. Burak Yikilmaz	Developing a Seismic Velocity Model of the Central Valley, Northern California ($56,095; March 2016 through February 2017	University of California Davis

Award No.	Principal Investigator(s)	Project Title	Institution
G16AP00096	Luther Strayer	CSU, East Bay-USGS Collaborative Study: 3-D Structure of the Hayward and Chabot Faults, Eastern San Francisco Bay, California ($83,013; March 2016 through August 2017)	California State University East Bay
G16AP00096	Luther Strayer	CSU, East Bay-USGS Collaborative Study: 3-D Structure of the Hayward and Chabot Faults, Eastern San Francisco Bay, California ($83,013; March 2016 through August 2017)	California State University East Bay
G16AP00097	Whitney Behr	Quaternary Geologic Slip Rates along the Agua Blanca Fault: Implications for Seismic Hazard to southern California and northern Baja California ($76,504; March 2016 through December 2017)	University of Texas Austin
G16AP00099	Andreas Skarlatoudis, Paul Somerville, CB Crouse & Mehrdad Hosseini	Feasibility of Uniformly Applicable Basin Amplification Models for the United States ($68,254; March 2016 through June 2018)	AECOM Technical Services, Inc.
G16AP00100	Craig Nicholson	An Integrated Onshore-Offshore Re-Evaluation of 3D Fault and Fold Geometry, Coastal Uplift and Seismic Hazard in the Santa Barbara-Ventura Area ($48,933; March 2016 through July 2017)	University of California Santa Barbara
G16AP00102	Paul Wetmore & Timothy Dixon	Terrestrial Cosmogenic Nuclide Dating for Determining Slip Rates along Calico Fault, Eastern California Shear Zone: Collaborative Research with University of South Florida and University of Cincinnati ($22,401; March 2016 through March 2017)	University of South Florida
G16AP00103	Lewis Owen	Terrestrial Cosmogenic Nuclide Dating for Determining Slip Rates along Calico Fault, Eastern California Shear Zone: Collaborative Research with University of South Florida and University of Cincinnati ($39,126; March 2016 through March 2017)	University of Cincinnati
G16AP00104	Nathan Toke & Daniel Horns	Characterizing the Timing of Ruptures Crossing the Boundary Between the Provo and Salt Lake City Segments of the Wasatch Fault ($31,366; May 2016 through May 2017)	Utah Valley University
G16AP00105	Yehuda Ben-Zion	Multi-Scale/Signal Imaging of the San Andreas System in the South-Central Transverse Ranges ($166,527; April 2016 through March 2018)	University of Southern California
G16AP00106	Ares Rosakis & Nadia Lapusta	Laboratory Earthquakes Along Interfaces with Rock Gouge ($90,000; April 2016 through March 2017)	California Institute of Technology
G16AP00107	Gail Atkinson	Ground Motion Characterization of Induced Earthquakes ($43,500; April 2016 through March 2017)	Gail Atkinson
G16AP00109	John Louie	Estimation of Three-Dimensional Basin Geometry in Reno, Nevada from Waveform Inversion ($33,604; April 2016 through April 2018)	University of Nevada, Reno
G16AP00111	Clifford Thurber	Nonvolcanic Tremor and Shear Wave Velocity Structure of the Crust in the Parkfield Region ($79,872; May 2016 through December 2017)	University of Wisconsin Madison
G16AP00115	William Barnhart	Characterizing Human Induced Seismicity and Deformation through Space Geodetic Methods ($34,734; May 2016 through October 2017)	University of Iowa

Award No.	Principal Investigator(s)	Project Title	Institution
G16AP00116	John Anderson & Glenn Biasi	Procedures for Using UCERF3 in Site-Specific Seismic Hazard Analyses in California ($69,071; May 2016 through May 2018)	University of Nevada Reno
G16AP00117	Nadia Lapusta	Earthquake Rupture Propagation into Creeping Areas of the San Andreas Fault ($90,000; May 2016 through April 2017)	California Institute of Technology
G16AP00118	Ronald Andrus	Liquefaction Probability Analysis of Pleistocene Deposits in the Greater Charleston, SC Area($59,932; May 2016 through August 2018)	Clemson University
G16AP00119	Jayne Bormann & Graham Kent	Constraining the Paleoseismic History and Maximum Event Magnitude for the San Diego Trough Fault Zone ($82,036; May 2016 through April 2018)	University of Nevada Reno
G16AP00127	Leonardo Seeber	Near-Shore Evaluation of Holocene Faulting and Geohazard in the New York City Metropolitan Region: Collaborative Research with University of Rhode Island and Columbia University ($22,800; May 2016 through April 2017)	Columbia University
G16AP00128	John King & Marie-Helene Cormier	Near-Shore Evaluation of Holocene Faulting and Geohazard in the New York City Metropolitan Region: Collaborative Research with University of Rhode Island and Columbia University ($56,735; May 2016 through April 2017)	University of Rhode Island
G16AP00138	Shahram Pezeshk	Hybrid Empirical Ground-Motion Prediction Equations for the Gulf Coast Region ($54,430; June 2016 through May 2017)	The University of Memphis
G16AP00139	Matt Heller	Investigation of Brittle Structures and Soft Sediment Deformation Associated with Paleoseismicity along the Lakeside and Little Fork Church Faults in Center Virginia Seismic Zone: Collaborative Research with the Virginia Dept. of Mines, Minerals, and Energy and the USGS ($55,093; June 2016 through May 2017)	Virginia Department of Mines, Minerals and Energy
G16AP00140	Michael Brudzinski	Discerning and Characterizing Induced Seismicity in Texas using Multistation ($50,737; June 2016 through December 2017)	Miami University
G16AP00141	Jefferson Chang	Paleoseismic & Geophysical Evaluations to Improve Seismogenic Source Characterization of the Meers Fault, OK: Collaborative Research with Portland State University and the University of Oklahoma ($49,295; June 2016 through November 2017)	University of Oklahoma
G16AP00142	Ashley Streig	Paleoseismic & Geophysical Evaluations to Improve Seismogenic Source Characterization of the Meers Fault, OK: Collaborative Research with Portland State University and the University of Oklahoma ($73,318; June 2016 through November 2017)	Portland State University
G16AP00143	Patrick Williams	Pilot Study: Extending the Rodgers Creek Rupture History, Trench Investigation at Santa Rosa ($38,800; August 2016 through November 2018)	Patrick Williams & Associates
G16AP00147	Egill Hauksson	Analysis of Earthquake Data from the Greater Los Angeles Basin and Adjacent Offshore Area, southern California ($75,000; July 2016 through June 2017)	California Institute of Technology
G16AP00148	Peter Shearer	Analysis of southern California Seismicity Using: (1) Swarms as Transient Detectors, (2) Coda Waves for Q Structure and Source Properties ($78,819; July 2016 through June 2017)	University of California San Diego

Award No.	Principal Investigator(s)	Project Title	Institution
G16AP00149	Simon Engelhart	Paleoseismology of a Currently Creeping Section of the Eastern Aleutian Subduction Zone: Collaborative Research with University of Rhode Island and U.S. Geological Survey ($74,957; July 2016 through September 2017)	University of Rhode Island
G16AP00150	Sean Gulick	Integrative Onshore-Offshore Fault Mapping and Hazard Assessment, Icy Bay, Southeast Alaska ($103,644; July 2016 through August 2017)	University of Texas Austin
G16AP00170	William Burns & Ian Madin	Investigation of Cascadia Earthquake Triggered Landslides: Collaborative Research with DOGAMI and University of Oregon ($60,113; September 2016 through August 2017)	Oregon Department of Geology and Mineral Industries (DOGAMI)
G16AP00171	Joshua Roering	Investigation of Cascadia Earthquake Triggered Landslides: Collaborative Research with DOGAMI and University of Oregon ($33,831; September 2016 through November 2017)	University of Oregon
G16AP00172	Michael Germeraad	Bay Area Vulnerable Housing Field Guide ($45,353; September 2016 through August 2018)	Association of Bay Area Governments
G16AP00181	Jonathan Stewart	Site database and Site Amplification for NGA-Subduction Project ($55,000; September 2016 through December 2018)	University of California Los Angeles
G16AP00189	Sinan Akciz	Paleoseismic Investigation of the Van Matre Ranch Site, Carrizo Plain, CA ($67,238; September 2016 through August 2018)	California State University Fullerton

4.3 National Earthquake Conference

Owing to the participation of science, policy and practice leaders, the National Earthquake Conference (NEC), is considered one of the most impactful events for the nation's seismic community. The May 2016 event received coverage from several news outlets including the Los Angeles Times and the British Broadcasting Corporation (BBC).

The NEC is held every four years and brings together emergency managers, policy makers, scientists, engineers, and businesses to exchange ideas and best practices concerning risk reduction strategies for seismic events. The May 2016 NEC brought together worldwide experts; inspired an immediate increase in financial support for earthquake safety research; and generated an ongoing, global dialogue about challenges the U.S. faces with seismic risk. FEMA, FLASH, and other earthquake partners hosted the NEC May 4 to 6 in Long Beach, California. More than 370 individuals attended, representing 220 organizations and 35 States and the U.S. Territories of American Samoa, Guam, and Puerto Rico. The conference theme asked, "What's New? What's Next? What's Your Role in Building a National Strategy?"

As a result of collaboration by the NEC advisory committee which included CUSEC, CREW, EERI, NEHRP, NESEC, PEER, SCEC, USGS, and WSSPC, the conference garnered unprecedented traditional news coverage (382 news features), leadership engagement, and social media coverage (2,491 posts and 3.6 million impressions for #NEC2016 over a three-day period). It helped focus key policymakers on top priorities and has generated positive policy outcomes.

The event resulted in the creation of the National Earthquake Resiliency Coalition, which will work toward helping the nation realize an earthquake-resilient future. On behalf of the newly created coalition, FLASH released twenty NEC presentations and findings in a public YouTube channel and an ongoing bi-monthly newsletter highlighting earthquake research, programs, and initiatives of NEC stakeholders.

Based on information presented at the event, the Governor of California sought an additional $10M in state funding to further the development of the state's EEW system.

FEMA participation in the conference included the FEMA Earthquake Program exhibit booth, where several hundred publications were distributed. In addition, FEMA staff did presentations on the South Napa Earthquake, the FEMA P-1024 publication and the two South Napa Recovery Advisories.

Section 5 - Major Earthquakes in FY 2016

Globally there were 15,397 earthquakes of M4.0 or greater in FY 2016. This worldwide activity is consistent with prior year averages of about 40 earthquakes per day of M4.0, or about 14,500 annually. There were 17 earthquakes worldwide with a M7.0 or higher. In FY 2016, earthquakes caused approximately 1,339 deaths, with the deadliest earthquake being the M7.8 Muisne (or Pedernales), Ecuador event on April 16, 2016 resulting in 673 casualties. The largest earthquake in the United States during FY 2016 was the M7.1 Iniskin earthquake in south-central Alaska, on January 24. Due to its location and intermediate depth (about 120 km) within the tectonic subduction zone beneath Alaska, this event caused no casualties and only minor damage.

In the central United States, seismicity rates in Kansas, Oklahoma, and Texas began to decline in FY 2016, with 21 earthquakes of M4.0 and greater in Kansas, Oklahoma and Texas, compared to 32 in 2015. The USGS recorded 672 M3.0 or larger earthquakes in this region. Although the number of seismic events in the region declined, Oklahoma experienced three M5.0 or larger earthquakes, which resulted in a significant moment release for the region. The M5.0 Cushing, Oklahoma earthquake on November 7 and the M5.8 Pawnee, Oklahoma earthquake on September 3 did damage to nearby towns. A M5.1 earthquake near Fairview, Oklahoma on February 13 caused no damage in a remotely populated area. All three of these events are attributed to wastewater disposal into underground rock formations from oil and gas recovery operations.[9]

Ecuador

The April 16, 2016 M7.8 earthquake, offshore of the west coast of northern Ecuador, occurred as the result of shallow thrust faulting on or near the plate boundary between the Nazca and South America plates. The location and mechanism of the earthquake are consistent with slip on the primary plate boundary interface, or megathrust, between these two major plates. Estimated casualties from this earthquake are approximately 668 deaths and more than 27,000 injured.[10] Overall, the population in this region resides in structures that are vulnerable to earthquake shaking, though some resistant structures exist. The predominant vulnerable building types are unreinforced brick masonry and mud wall construction.

Ecuador has a history of large subduction zone related earthquakes. Seven M7.0 or greater earthquakes have occurred within 250 km of this event since 1900. On May 14th, 1942, a M7.8 earthquake occurred 43 km south of the April 16, 2016 event. On January 31, 1906, a M8.3 earthquake (reportedly as large as M8.8 in some sources) nucleated on the subduction zone interface 90 km to the northeast of the April 2016 event, and ruptured over a length of approximately 400-500 km, resulting in a damaging tsunami that caused somewhere between 500 and 1,500 fatalities. The April 2016 earthquake occurred at the southern end of the approximate rupture area of the

[9] See https://earthquake.usgs.gov/research/induced/

[10] See https://earthquake.usgs.gov/earthquakes/eventpage/us20005j32#impact

1906 event. A shallow, upper crustal M7.2 earthquake 240 km east of the April 2016 event on March 6, 1987 resulted in approximately 1,000 fatalities.[11]

Conclusion

The impact of the Ecuador earthquake demonstrates important lessons relevant to NEHRP goals and objectives. This earthquake demonstrates that earthquake preparedness and long-term mitigation measures, such as implementing building design and construction practices based on earthquake resistant standards or codes, remain a key factor in avoiding human and material losses as a result of earthquake hazards.

[11] See https://earthquake.usgs.gov/earthquakes/eventpage/us20005j32#executive

Section 6 - Related Activities Supporting NEHRP Goals

Public Law 108–360, the National Earthquake Hazards Reduction Program Reauthorization Act of 2004, requires that NEHRP's annual report to Congress include a description of activities being carried out by the NEHRP agencies that contribute to the program, but are not included in the program. 42 U.S.C. § 7704(a)(4)(E). Highlights of these programs and activities are described below.

6.1 EarthScope

EarthScope is a multidisciplinary earth science program aimed at exploring, in unprecedented detail, the four-dimensional structure, dynamics, and evolution of the North American continent. EarthScope is supported by NSF, in partnership with the USGS and the National Aeronautics and Space Administration. The EarthScope Facility was composed of three core components: the Plate Boundary Observatory (PBO), constructed and operated by the University of NAVSTAR Consortium (UNAVCO); the San Andreas Fault Observatory at Depth (SAFOD), constructed by Stanford University in cooperation with USGS, and operated from 2008-2013 by UNAVCO; and the United States Seismic Array (USArray), constructed and operated by IRIS. Deployment of Transportable Array (TA) stations in the continental U.S. ended in FY 2015. At that time testing and planning for TA deployment in the challenging environment of Alaska stated. By the end of FY 2016 about 100 TA stations were deployed in Alaska. All USArray data is available in almost real-time.

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

The EarthScope Facility has compiled data, operational stations, and physical samples that are all being used for NEHRP-related research and operational activities today. For example, the Central and Eastern United States Seismic Network project, which began in FY 2013 with funding from NSF and USGS, has converted 158 USArray TA stations to long-term operations and upgraded the instrumentation and data collection to support critical infrastructure monitoring and other needs. These stations will be jointly supported through FY 2017, at which point their long-term operation will be unfunded. These stations greatly increase the density of long-term, continuously recording seismic stations in the region, providing more accurate locations, depths and size estimates faster, and earthquake locations, as well as more ground motion records being obtained from the finer instrument placement.

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

NSF, in collaboration with the USGS, continues to oversee the SAFOD project. Since 2009, the USGS has been operating a seismic station deployed above a series of repeating earthquakes occurring at a depth of 3 km. Recording these events helps USGS understand the inner workings of earthquake initiation on this major plate boundary fault. NSF supports archiving and distribution of physical samples of the deep fault materials obtained in 2007 during the drilling stage of SAFOD; researchers around the world are analyzing these samples to understand a variety of physical properties related to fault deformation and earthquake generation. NSF supports this activity through an award to Texas A&M University.

6.2 Subcommittee on Disaster Reduction

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

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

6.3 International Activities

Cooperation with Japan

The US-Japan Panel on Earthquake Research, or UJNR, promotes advanced research toward a more fundamental understanding of the earthquake process and hazard estimation. These exchanges are beneficial in furthering cooperation and deepening understanding of problems common to both Japan and the U.S. In FY 2016, the USGS worked with Japanese counterparts to plan the Eleventh Joint meeting in Napa Valley, California, November 16-18, 2016.[12]

[12] Proceedings of the 11th United States-Japan Natural Resources Panel for Earthquake Research can be found at https://pubs.usgs.gov/of/2017/1133/ofr20171133.pdf

Appendix - List of Acronyms and Abbreviations

ACEHR	Advisory Committee on Earthquake Hazards Reduction
ACI	American Concrete Institute
AISI	American Iron and Steel Institute
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
CEUS	Central and Eastern U.S.
CGS	Colorado Geological Survey
CMMI	(NSF) Civil, Mechanical and Manufacturing Innovation Division
CREW	Cascadia Region Earthquake Workgroup
CRSC	Code Resource Support Committee
CUSEC	Central United States Earthquake Consortium
DOLA	(Colorado) Department of Local Affairs
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
GAGE	Geodesy Advancing Geosciences and EarthScope
GSN	Global Seismographic Network
HAZUS	Hazards U.S.
ICSSC	Interagency Committee on Seismic Safety in Construction
IRC	International Residential Code
IRIS	Incorporated Research Institutions for Seismology
M	magnitude
$M	(dollars) million

NEC	National Earthquake Conference
NEES	George E. Brown, Jr. Network for Earthquake Engineering Simulation
NEHRP	National Earthquake Hazards Reduction Program
NEIC	(USGS) National Earthquake Information Center
NESEC	Northeast States Emergency Consortium
NGEO	National Geophysical Observatory for Geoscience
NHC	Natural Hazards Center
NHERI	Natural Hazards Engineering Research Infrastructure
NIST	National Institute of Standards and Technology
NSHM	(USGS) National Seismic Hazard Maps
NSF	National Science Foundation
NSMP	(USGS) National Strong Motion Project
OEM	(Oregon) Office of Emergency Management
OMB	Office of Management and Budget
OSTP	White House Office of Science and Technology Policy
PBO	Plate Boundary Observatory
PBSD	performance-based seismic design
PCWG	(NEHRP) Program Coordination Working Group
PEER	Pacific Earthquake Engineering Research Center
PPD	Presidential Policy Directive
PUC	Provisions Update Committee
QCN	Quake Catcher Network
R&D	research and development
RAPID	(NSF) Rapids Response Research funding mechanism
REU	Research Experiences for Undergraduates
ROVER	Rapid Observation of Vulnerability and Estimation of Risk
RVS	(Missouri) Rapid Visual Screening
S&E	salaries and expenses
SAFOD	San Andreas Fault Observatory at Depth
SAGE	Seismological Facilities for the Advancement of Geosciences and EarthScope
SCEC	Southern California Earthquake Center
SCEMD	South Carolina Emergency Management Division
SDR	Subcommittee on Disaster Reduction

SEI	Structural Engineering Institute
TA	Transportable Array
UNAVCO	University of NAVSTAR Consortium, nonprofit university-governed consortium that facilitates geosciences research using geodesy
URM	Unreinforced Masonry
USArray	United States Seismic Array
USGS	United States Geological Survey
WSSPC	Western States Seismic Policy Council