Biennial Report of the National Earthquake Hazards Reduction Program

For Fiscal Years 2018 and 2019

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FEMA

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

USGS
science for a changing world

This report covers the National Earthquake Hazards Reduction Program (NEHRP or Program) activities during fiscal years (FY) 2018 and 2019. It is submitted to the Congress by the Interagency Coordinating Committee on Earthquake Hazards Reduction (Interagency Coordinating Committee), as required by the Earthquake Hazards Reduction Act of 1977 (Public Law 95-124, 42 U.S.C. 7701 *et. seq.*), as amended by the NEHRP Reauthorization Act of 2004 (Public Law 108-360), and as amended by the NEHRP Reauthorization Act of 2018 (Public Law 115-307).

The members of the Interagency Coordinating Committee are as follows:

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Table of Contents

Executive Summary

Public Law 115-307 requires the Interagency Coordinating Committee submit a biennial report to Congress on the budgets and activities of the National Earthquake Hazards Reduction Program (NEHRP), also referred to hereafter as 'Program'.[1] Pursuant to the requirement, the Interagency Coordinating Committee is submitting this biennial report, through NEHRP agency leadership, covering the fiscal year (FY) 2018 and FY 2019[2] activities of the four NEHRP agencies[3] and their progress toward reducing the consequences of future earthquakes in the United States (U.S.). This report also summarizes actual NEHRP-related budgets by agency for FY 2018 and FY 2019 and Program budgets requested by the Administration for FY 2020.

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

Significant accomplishments by the NEHRP agencies during FY 2018-19 are given below.

FEMA. During FY 2018-19, FEMA completed several new technical design guidelines that will significantly assist in the design and construction of new buildings and the assessment and retrofitting of at-risk older structures. These publications[4] include:

- *Seismic Performance Assessment and Design of Buildings*: Volumes 1-7 (FEMA P-58)
- *Vulnerability-Based Seismic Assessment and Retrofit of One- and Two-Family Dwellings* (FEMA P-1100)
- *Example Application Guide for the American Society of Civil Engineers (ASCE)/Structural Engineering Institute (SEI) 41-13 Seismic Evaluation and Retrofit of Existing Buildings; with Additional Commentary for ASCE/SEI 41-17* (FEMA P-2006)
- *Assessing Seismic Performance of Buildings with Configuration Irregularities* (FEMA P-2012)
- *Seismic Evaluation of Older Concrete Buildings for Collapse Potential* (FEMA P-2018)
- *Guidelines for Design of Structures for Vertical Evacuation from Tsunamis*, Third Edition (FEMA P-646)

In FY 2019, the new legislation mandated several changes to the administration of the agency's NEHRP State Assistance Program (Earthquake Direct State Assistance), the most significant of which was the elimination of the graduated "hard" cash match requirement contained in 44 C.F.R.

[1] This report is being submitted for FY 2018 and FY 2019. In FY 2018, the NEHRP Act (42 U.S.C. §§ 7701 *et seq.*) was amended.

[2] This report covers FY 2018 and FY 2019 as defined by the Federal Government, a period that began on October 1, 2017, and ended on September 30, 2019.

[3] The four Federal agencies participating in NEHRP are the Federal Emergency Management Agency (FEMA), the National Institute of Standards and Technology (NIST), the National Science Foundation (NSF), and the U.S. Geological Survey (USGS).

[4] Visit https://www.fema.gov/emergency-managers/risk-management/building-science/earthquakes?combine=&page=4 to search for FEMA Building Science publications.

Part 361. The new legislation brings the FEMA NEHRP State Assistance Program in line with FEMA's other non-disaster hazard mitigation grants, in that it now only requires the state to provide a 25% cost share and allows for the use of "in-kind" contributions. These changes removed a major obstacle for many of the 36 eligible states and will encourage them to participate in the grant program going forward. In addition, this change will enable FEMA to further enhance program participation by retiring the "state support" component of the FEMA NEHRP State Assistance Program.

NIST. As the lead agency for NEHRP, NIST supported the multiple meetings of the Interagency Coordinating Committee and the Advisory Committee on Earthquake Hazards Reduction. Further, Executive Order (EO) 13717, summarized in Appendix B, required NIST to report on federal agency compliance with the EO. A summary of the received agency progress reports is contained in NIST Technical Note (TN) 2136-1[5] . In addition, NIST started work on an update to *Standards of Seismic Safety for Existing Federally Owned and Leased Buildings* for the Interagency Committee on Seismic Safety in Construction (ICSSC). NIST supported NEHRP partner agencies by hosting monthly Program Coordination Working Group (PCWG) meetings. Further, NIST contributed technical expertise to review other NEHRP agency solicited and unsolicited proposals. NIST funded and managed several grantees through the Disaster Resilience Research Grants Program (see Appendix A).

During FY 2018-19, NIST sustained its support for the development of national building codes and engineering standards in an effort to mitigate the risks posed to the built environment and society-at-large from earthquakes. NIST provided technical leadership and expertise to Standards Development Organizations (SDOs) to advance ASCE 7: *Minimum Design Loads and Associated Criteria for Buildings and Other Structures* (ASCE 2022)[6] and ASCE 41: *Seismic Rehabilitation of Existing Buildings* (ASCE 2023)[7], while further providing management leadership to the development of new engineering standards, ACI 369: *Guide for Seismic Rehabilitation of Existing Concrete Frame Buildings and Commentary* (ACI 2022)[8] and AISC 342: *Seismic Provisions for Evaluation and Retrofit of Existing Structural Steel Buildings* (AISC 2022)[9], which focus on assessment and retrofit of concrete and steel structural building components, respectively.

Senate Report 114-239[10] mandated NIST to submit to Congress a plan detailing the basic research, applied research, and implementation activities necessary to develop a new ``immediate occupancy'' (IO) safety building performance objective for commercial and residential properties, as well as the engineering design principles needed to fulfill this objective.

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[5] See https://doi.org/10.6028/NIST.TN.2136-1.

[6] American Society of Civil Engineers (ASCE), 2022. *Minimum Design Loads for Buildings and Other Structures*, ASCE/SEI 7-22, Reston, VA. *In development.*

[7] American Society of Civil Engineers (ASCE), 2017. *Seismic Evaluation and Retrofit of Existing Buildings*, ASCE/SEI 41-23, Reston, VA. *In development.*

[8] American Concrete Institute (ACI), 2022. *Standard Requirements for Seismic Evaluation and Retrofit of Existing Concrete Buildings and Commentary*, ACI 369.1-22, Farmington Hills, MI. *In development.*

[9] American Institute of Steel Construction (AISC), 2022. *Seismic Provisions for the Evaluation and Retrofit of Existing Steel Building*, ANSI/AISC 342-22, Chicago, IL. *In development.*

[10] See https://www.congress.gov/congressional-report/114th-congress/senate-report/239.

This mandate expanded the application of IO performance beyond critical buildings, such as hospitals, to other buildings that are important to residents, businesses, and the broader community. NIST, working with the Science and Technology Policy Institute, held a national stakeholder workshop on January 16-17, 2018, to discuss issues related to IO. A steering committee of nine members was established to provide individual subject matter expertise. In August 2018, NIST published Special Publication 1224[11] which presents an exploratory, interdisciplinary assessment of activities needed to target a higher level of building performance. Also, in support of its NEHRP mission, NIST conducted several research projects that focused on the development of new or updated modeling characteristics for structural and nonstructural components used in the analytical model of a structure to evaluate forces and deformations to compare with a desired performance in performance-based seismic design (PBSD). Further, NIST continued to investigate the usage of high-strength materials for concrete components and evaluating methods and algorithms to measure the analytical collapse resistance of buildings.

In January 2019, NIST sent an internal team of earthquake experts to evaluate the consequences from the November 30, 2018 M7.1 earthquake near Anchorage, Alaska. An NSF-funded research team worked in coordination with the NIST researchers, collecting data relevant to the performance of retrofit buildings. Data acquired will provide information for research to support response to and recovery from earthquakes. In an unrelated NIST project, additional buildings from Mexico City and elsewhere were added in FY 2019 to an on-going study undertaken by the Applied Technology Council (ATC) to study buildings or test structures shaken by actual earthquake motions and in turn evaluate them using ASCE 41. The ATC study and Anchorage earthquake data will help NIST in its effort to benchmark U.S. codes and standards to determine how accurate present assessment methods are in predicting damage.

NIST also promoted implementation of earthquake-resilient measures in professional practice and in private and public policies by disseminating research findings through invited technical lectures, webinars, and presentations, at conferences and committee meetings, and in peer-reviewed publications.

NSF. During FY 2018-19, NSF awarded over 250[12] grants to individual researchers and centers for fundamental research in the Earth sciences, engineering, computational, and social, behavioral, and economic sciences relevant to advancing understanding of the causes and impacts of earthquakes. NSF provided funding for the Global Seismographic Network (GSN) in coordination with the USGS. The GSN provides timely, state-of-the art digital information about seismic activity around the world. NSF and USGS also jointly supported the Southern California Earthquake Center (SCEC). SCEC coordinates the relevant research communities to identify research priorities in seismology, tectonic geodesy, earthquake geology, and related interdisciplinary studies, including computational science and modeling. Leveraging funds from NSF, USGS, and other SCEC

[11] See https://doi.org/10.6028/NIST.SP.1224.

[12] NSF Award Search results are available at https://www.nsf.gov/awardsearch/advancedSearchResult?PIId=&PIFirstName=&PILastName=&PIOrganization=&PIState=&PIZip=&PICountry=&ProgOrganization=&ProgEleCode=&BooleanElement=All&ProgRefCode=&BooleanRef=All&Program=&ProgOfficer=&Keyword=earthquake&AwardNumberOperator=&AwardAmount=&AwardInstrument=&ActiveAwards=true&ExpiredAwards=true&OriginalAwardDateOperator=Range&OriginalAwardDateFrom=10%2F1%2F2017&OriginalAwardDateTo=9%2F30%2F2019&StartDateOperator=&ExpDateOperator=

partners, the Center funded more than 200 research projects addressing the community-defined research priorities across FY 2018-19.

NSF continued to support the Natural Hazards Engineering Research Infrastructure (NHERI), a distributed, multi-user, national network of research facilities that provides the natural hazards engineering community with access to research infrastructure including earthquake and wind engineering experimental facilities, cyberinfrastructure (which includes a repository for scientifically significant natural hazard-related data), and computational modeling and simulation tools, coupled with educational and community outreach activities. NSF provided $16.31 million to the University of California San Diego to upgrade its large, high performance outdoor shake table (LHPOST), which is a NHERI facility, from one degree of freedom to a full six degrees of freedom capability.

In FY 2018, NSF supported the establishment of the Structural Extreme Events Reconnaissance network at the University of Notre Dame to support academic researchers to develop community-driven standards, best practices, training, and coordinated field work for structure-relevant data collection following an extreme earthquake or windstorm event. In FY 2019, NSF directly supported a number of unsolicited research proposals from scientists spread across the nation who proposed highly competitive and compelling research to advance our basic understanding of earthquake processes and impacts. NSF also funded rapid-response research teams to examine seismic, geologic, geotechnical, engineering, and societal issues raised by the 2018 Anchorage, Alaska earthquake and the 2019 Ridgecrest, California earthquake.

USGS. During FY 2018-19, the USGS and partners continued to develop and implement the ShakeAlert earthquake early warning (EEW) system as a new product of the USGS Advanced National Seismic System (ANSS) in the three west coast states (CA, OR, and WA). USGS updated and revised its National Seismic Hazard Model (NSHM), which provides the expected ground shaking level for the conterminous U.S., and delivered the revised model to engineering groups responsible for updating the model building codes and referenced standards. The USGS also conducted field investigations in the areas of M7.1 earthquakes near Anchorage, Alaska and Ridgecrest, California.

Section 1 – Introduction

This FY 2018-19 NEHRP biennial report provides an overview of NEHRP agency budgets, a description of the statutory Program activities, State activities, and non-NEHRP related activities that support NEHRP goals, identified in the NEHRP Strategic Plan[13]. This report and prior NEHRP annual reports are available at https://www.nehrp.gov/about/reports.htm.

The NEHRP is a four-agency program established by Congress "to reduce the risks of life and property from future earthquakes and increase the resilience of communities in the U.S."[14] A primary role of NEHRP is to provide leadership and resources for developing new, cost-effective measures to reduce the damage and disruption that earthquakes cause, and to advocate for their implementation. NIST serves as the lead agency. The NEHRP agencies have distinct roles and responsibilities that are mutually supportive. There is close coordination and collaboration between agencies, instead of an overlap or duplication of effort. In fact, completion of tasks by one NEHRP agency often depend on the data, assessments, and research generated by another. NEHRP continues to encourage research and data sharing amongst researchers and institutions, and provides the important link to implementation throughout communities with seismic risk in the U.S. and territories.

The Interagency Coordinating Committee on Earthquake Hazards Reduction 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.

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

NIST's mission is to promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life. NIST serves as the lead agency for NEHRP and supports both the Interagency Coordinating Committee that oversees the planning, management, and coordination of the Program and the Advisory Committee on Earthquake Hazards Reduction (ACEHR) that assesses the Program. ACEHR shall report to the NIST Director at least once every two years on its findings of the Program assessment. The full text of the ACEHR recommendations and corresponding responses from the NEHRP agencies are available on the NEHRP website.[15] In addition to the lead agency responsibilities, NIST carries out research and development to improve

[13] The *Strategic Plan for the National Earthquake Hazards Reduction Program, Fiscal Years 2009–2013* (http://nehrp.gov/pdf/strategic_plan_2008.pdf), was published in October 2008 and will be updated in FY 2021.
[14] 42 U.S.C. § 7702.
[15] See https://www.nehrp.gov/pdf/ACEHRLetter_Mar18mtg_v6%20FINAL.pdf, https://www.nehrp.gov/pdf/NIST%20response%20to%20March%202018%20ACEHR%20interim%20report.pdf, https://www.nehrp.gov/pdf/ACEHR%20signed%20interim%20letter_May2019.pdf, https://www.nehrp.gov/pdf/NIST%20Response%20to%2005-09-19%20ACEHR%20Interim%20Report%20Ltr.pdf, https://www.nehrp.gov/pdf/September_2019_ReporttotheNISTDirector.pdf, and https://www.nehrp.gov/pdf/NEHRP%20Responses_09-26-19%20ACEHR%20report_FINAL.pdf.

resilience through advancing building codes and standards and construction practices for structures and lifelines. In doing so, NIST develops and conducts applied research to evaluate and test earthquake-resistant design and construction practices for implementation into building codes and engineering practice.

NSF supports fundamental research and research facilities in Earth sciences, engineering, computational, and social, behavioral, and economic sciences relevant to improved understanding of the causes and impacts of earthquakes and to the development of effective measures to reduce their effects. This support is carried out primarily through research grants or cooperative agreements to individual universities, university consortia, and other organizations.

USGS conducts earthquake monitoring nationally and worldwide to provide the Nation with timely earthquake notifications, impact estimates, and scientific information; prepares regional and national seismic hazard assessments; conducts targeted fundamental and applied research to improve these functions; and coordinates post-earthquake investigations.

Section 2 – Program Budgets

The *Strategic Plan for the National Earthquake Hazards Reduction Program, Fiscal Years 2009–2013*, published in October 2008[16], defined three major strategic goals for NEHRP that encompass all but one of the Program activities defined in Public Law 108–360. The remaining activity, which concerns the development, operation, and maintenance of the NEHRP facilities, was incorporated directly into the strategic plan. Table 2.1 shows the relationships between the congressionally-defined program activities and the goals and activities that are included in the strategic plan.

Table 2.1 – *RELATIONSHIPS of NEHRP STRATEGIC GOALS to STATUTORY PROGRAM ACTIVITIES*

NEHRP Strategic Goals	Statutory Program Activities*
Goal A: Improve the 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 decisions 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 the Advanced National Seismic System (ANSS), the Natural Hazards Engineering Research Infrastructure (NHERI)[17], and the Global Seismographic Network (GSN). 42 U.S.C. § 7704(a)(2)(D).

*As defined by Congress in 42 U.S.C. § 7704.

42 U.S.C. § 7704(a)(4)(A) requires the NEHRP biennial report to include, for each agency participating in the Program and for each Program activity defined in the legislation, the Program budget by agency when the report was developed (i.e., the FY following the period covered in the report) and the requested program budget by agency for the next FY.[18] Program budgets by agency

[16] Because the NEHRP Strategic Plan (http://nehrp.gov/pdf/strategic_plan_2008.pdf) was based on funding levels exceeding appropriated levels, the plan continues to be relevant and remains in effect. It will be updated in accordance with the provisions of any future NEHRP reauthorization, or as future need for additional strategic planning may dictate.

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

[18] 42 U.S.C. § 7704(a)(4).

for the reporting periods (FY 2018 and FY 2019) are presented in Tables 2.2 and 2.3 and show 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 for FY 2020. Funding for the development, operation, and maintenance of NEHRP facilities supports the ANSS, NHERI, and the GSN.

2.1 NEHRP Enacted FY 2018 and FY 2019 Budgets by Agency and Strategic Goal

Table 2.2 lists the FY 2018 NEHRP budgets and Table 2.3 lists the FY 2019 NEHRP budgets, by strategic goal, for the four NEHRP agencies: FEMA, NIST, NSF, and USGS.

Table 2.2 – *NEHRP AGENCY BUDGETS for FY 2018*

Strategic Goal	FY 2018 Funds Allocated to Goal ($M)[1]				
	FEMA	NIST[2]	NSF[3]	USGS[4]	**Total**
Goal A: Improve understanding of earthquake processes and impacts.	0.1		62.2	13.5	**75.8**
Goal B: Develop cost-effective measures to reduce earthquake impacts on individuals, the built environment, and society at large.	4.6	4.1		3.4	**12.1**
Goal C: Improve the earthquake resilience of communities nationwide.	3.8	0.3		17.2	**21.3**
Lead agency Program support		0.8			**0.8**
Develop, operate, and maintain NEHRP facilities:					
ANSS				49.3	**49.3**
GSN			3.5	6.7	**10.2**
Totals	**8.5**	**5.2**	**65.7**	**90.1**	**169.5**

Notes on Table 2.2:

[1] Enacted budgets include support for all NEHRP-related activities unless stated otherwise. Amounts are rounded to the nearest $0.1 million ($M).

[2] NIST budget includes support for the Earthquake Engineering Research and Development activities and $1.3M of Disaster Resilience Research Grants Program funding.

[3] NSF budget includes support for the NSF portion of the GSN ($3.5M) and the earthquake engineering portion of the NHERI, but excludes EarthScope funding and NSF headquarters (HQ) administrative expenses.

[4] USGS budget includes support for the USGS Earthquake Hazards Program (EHP) and the USGS portion of the GSN ($6.7M). The amount for ANSS ($49.3M) includes funding for the development and operation of the ShakeAlert Earthquake Early Warning (EEW) system. Congressional "one-time" funding is included, but figures exclude the $8.0M supplemental funding for seismic network restoration following Hurricane Maria.

Table 2.3 – *NEHRP AGENCY BUDGETS for FY 2019*

Strategic Goal	FY 2019 Funds Allocated to Goal ($M)[1]				
	FEMA	NIST[2]	NSF[3]	USGS[4]	**Total**
Goal A: Improve understanding of earthquake processes and impacts.	0.1		57.0	13.5	**70.6**
Goal B: Develop cost-effective measures to reduce earthquake impacts on individuals, the built environment, and society at large.	4.6	4.1		3.4	**12.1**
Goal C: Improve the earthquake resilience of communities nationwide.	4.0	0.3		17.2	**21.5**
Lead agency Program support		0.8			**0.8**
Develop, operate, and maintain NEHRP facilities:					
ANSS				49.3	**49.3**
GSN			3.5	6.7	**10.2**
Totals	**8.7**	**5.2**	**60.5**	**90.1**	**164.5**

Notes on Table 2.3:

[1] Enacted budgets include support for all NEHRP-related activities unless stated otherwise. Amounts are rounded to the nearest $0.1 million ($M).

[2] NIST budget includes support for the Earthquake Engineering Research and Development activities and $1.3M of Disaster Resilience Research Grants Program funding.

[3] NSF budget includes support for the NSF portion of the GSN ($3.5M) and the earthquake engineering portion of the NHERI, but excludes EarthScope funding and NSF headquarters (HQ) administrative expenses.

[4] USGS budget includes support for the USGS EHP and the USGS portion of the GSN ($6.7M). The amount for ANSS ($49.3M) includes funding for further development and operation of the ShakeAlert Earthquake Early Warning (EEW) system. Congressional "one-time" funding is included, but figures exclude the $8.0M supplemental funding for seismic network restoration following Hurricane Maria.

2.2 NEHRP FY 2020 Budget Requests by Agency and Strategic Goal

Table 2.4 lists the FY 2020 NEHRP planning budgets for each agency by strategic goal. These figures are based on agency submissions included in the President's FY 2020 budget request to Congress.

TABLE 2.4 – *NEHRP AGENCY BUDGET REQUESTS for FY 2020*

Strategic Goal	FY 2020 Funds Requested for NEHRP Goals ($M)[1]				
	FEMA	NIST[2]	NSF[3]	USGS[4]	**Total**
Goal A: Improve understanding of earthquake processes and impacts.	0.1		50.5	13.6	**64.2**
Goal B: Develop cost-effective measures to reduce earthquake impacts on individuals, the built environment, and society at large.	4.6	4.1		3.4	**12.1**
Goal C: Improve the earthquake resilience of communities nationwide.	3.8	0.3		19.9	**24.0**
Lead agency Program support		0.8			**0.8**
Develop, operate, and maintain NEHRP facilities:					
ANSS				27.4	**27.4**
GSN			3.5	6.7	**10.2**
Totals	**8.5**	**5.2**	**54.0**	**71.0**	**138.7**

Notes on Table 2.4:

[1] Budget requests include planned support for all NEHRP-related activities unless stated otherwise. Amounts are rounded to the nearest $0.1 million ($M).

[2] NIST budget request includes planned support for the Earthquake Engineering Research and Development activities and $1.3M of anticipated Disaster Resilience Research Grants Program funding.

[3] NSF budget request includes planned support for the NSF portion of the GSN ($3.5M) and the earthquake engineering portion of the NHERI budget, but excludes EarthScope funding and NSF HQ administrative expenses.

[4] USGS budget request includes planned support for the USGS EHP and the USGS portion of GSN ($6.7M).

Section 3 - NEHRP Activities by Strategic Goal

This section summarizes major activity highlights and accomplishments of NEHRP during FY 2018-19. The organization of this chapter follows the NEHRP strategic plan[19]. The strategic plan defines NEHRP activities in terms of broad strategic goals, more specific objectives, and related strategic priorities. The goals are directly linked to NEHRP activities defined in 42 U.S.C. § 7704(a)(2). By following the structure of the strategic plan, this report allows the reader to directly assess how accomplishments are furthering progress toward the Program's stated goals and objectives. Accomplishments are identified by the NEHRP agency but are cast in terms of collective progress towards the NEHRP goals.

3.1 Goal A: Improve Understanding of Earthquake Processes and Impacts

This strategic goal directly supports the congressionally defined NEHRP program activity, "Improve the understanding of earthquakes and their effects on communities, buildings, structures, and lifelines through interdisciplinary research that involves engineering, natural sciences, and social, economic, and decisions sciences."[20] In FY 2018-19, 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.

Fundamental Research Support (NSF)

During FY 2018-19, NSF awarded over 250 grants to individual researchers and centers for fundamental research in the Earth sciences, engineering, computational, and social, behavioral, and economic sciences relevant to advancing understanding of the causes and impacts of earthquakes. For example, a grant was awarded to Oregon State University (NSF award 1933217) to investigate how a large earthquake on the Cascadia Subduction Zone (CSZ) would impact the extent, distribution, and duration of the western electrical grid failure as a function of earthquake intensity and possible aftershocks; develop a framework for the identification of critical grid locations and components that will aid decision makers and planners, and also be broadly applicable to any seismic zone in the US; estimate expected initial load loss and load recovery time due to a major CSZ event; and explore impacts of Remedial Action Schemes on grid performance and recovery.

NSF provided funding for the GSN in coordination with the USGS. The GSN provides timely, state-of-the art digital information about seismic activity around the world. Its data are foundational for research into earthquake processes and impacts.

NSF and USGS also jointly supported the Southern California Earthquake Center (SCEC). SCEC coordinates the relevant research communities to identify research priorities in seismology, tectonic geodesy, earthquake geology, and related interdisciplinary studies, including computational science and modeling. Leveraging funds from NSF, USGS, and other SCEC partners, the Center funded more than 200 research projects addressing the community-defined research priorities across FY 2018-19.

[19] See http://nehrp.gov/pdf/strategic_plan_2008.pdf.

[20] 42 U.S.C. § 7704(a)(2)(C).

During FY 2018-19, NSF continued to support NHERI, a distributed, multi-user, national network of research facilities that provides the natural hazards engineering community with access to research infrastructure including earthquake and wind engineering experimental facilities, cyberinfrastructure (which includes a repository for scientifically significant natural hazard-related data), and computational modeling and simulation tools, coupled with educational and community outreach activities.

NSF provided $16.31 million during FY 2018-19 to the University of California San Diego to upgrade its large, high performance outdoor shake table (LHPOST), from its current one degree of freedom to a full six degrees of freedom capability. In its upgraded configuration of this NHERI facility, the LHPOST will be able to reproduce all six components of earthquake ground motion (two horizontal and one vertical translational components, as well as pitch, roll, and yaw rotational components). NSF also provided $3.0 million to the University of Colorado at Boulder to establish and support a new extreme events reconnaissance research leadership corps, CONVERGE, that connects researchers from different disciplines, develops best practice guidelines for reconnaissance research, and supports public communications in the event of a major disaster.

In FY 2018, NSF supported the establishment of the Structural Extreme Events Reconnaissance network at the University of Notre Dame to support academic researchers to develop community-driven standards, best practices, training, and coordinated field work for structure-relevant data collection following an extreme earthquake or windstorm event. In FY 2019, NSF directly supported a number of unsolicited research proposals from scientists spread across the nation who submitted highly competitive proposals for research to advance our basic understanding of earthquake processes and impacts. NSF also funded rapid-response research teams to examine seismic, geologic, geotechnical, engineering, and societal issues raised by the 2018 Anchorage, Alaska earthquake and the 2019 Ridgecrest, California earthquake sequence. NSF and USGS also funded the Earthquake Engineering Research Institute (EERI) to organize a one-year anniversary symposium in Anchorage, Alaska for the 2018 Alaskan earthquake and a workshop in Southern California on lessons-learned from the 2019 Ridgecrest earthquake sequence.

Evaluation of Large Earthquake Recurrence Intervals in the Pacific Northwest (USGS)

In FY 2018, the USGS launched a new project to evaluate the recurrence intervals of CSZ earthquakes. The CSZ lies just off the coast of the Pacific Northwest and has the potential for generating earthquakes, as large as magnitude (M)9, capable of causing widespread damage from strong ground shaking, landslides, and liquefaction, as well as devastating tsunamis. Shaking hazard estimates for future earthquakes rely on estimates of how often such earthquakes have occurred, as well as the magnitudes and extents of past earthquakes.

The CSZ last ruptured in January 1700, in a M9 earthquake, the widespread impacts of which included land-level changes and a tsunami that inundated sections of the Cascadia coastline and crossed the Pacific Ocean to be recorded in historical records in Japan.

To address these needs, this project is examining several new lines of evidence, including geologic records from multiple past earthquakes, coastal subsidence and uplift, tsunami deposits, turbidites (underwater landslides), disturbances in sedimentary sections, and onshore landslides.

Studies are also underway to provide constraints on the Cascadia plate-interface fault properties using geodetic data, earthquake source models, shaking from ground-motion modeling, and recorded data of strong ground motion. These constraints are being used in next-generation computer models of CSZ fault rupture and ground shaking.

This project, which is continuing into FY 2020, is conducted in partnership with university experts and with USGS science centers supported by the USGS Earthquake Hazards, Coastal and Marine Hazards and Resources, and Landslide Hazards Programs. Findings from this project will ultimately lead to an increase in accuracy of earthquake hazard and risk assessments in the Pacific Northwest.

Studies of the Ridgecrest, California Earthquake Sequence (USGS and NSF)

In FY 2019, the USGS responded to a pair of earthquakes that occurred near Ridgecrest, California on the China Lake Naval Air Weapons Station. A M6.4 earthquake occurred on July 4, 2019 and was followed 34 hours later by a more powerful M7.1 earthquake. Both earthquakes were felt strongly in the China Lake-Ridgecrest area, in Los Angeles, as far north as the San Francisco Bay Area, and as far east as Phoenix. The estimated ground shaking from the USGS ShakeMap revealed maximum shaking estimated at MMI IX (violent) near the epicenter and shaking was very strong (MMI VII) over a broader, approximately 25-mile wide region, including the city of Ridgecrest.

Reports of earthquake effects included building damage, fires, and reports of many objects that fell off shelves. Over 10,000 aftershocks were recorded and 44,781 "USGS Did You Feel It?" reports were received for the larger event. USGS work included conducting aerial and ground reconnaissance of the extensive surface rupture, deploying temporary seismic and geodetic stations to record aftershocks, and coordinating efforts with military, state, local and academic partners. NSF provided RAPID funding to deploy seismic arrays around the Naval Station including a post-earthquake LIDAR survey of the region. USGS field teams in the Ridgecrest area and on the China Lake Naval Air Weapons Station documented fault offsets through direct measurements using tools ranging from tape measures to mobile laser scanning devices.

Their observations show that the M7.1 event caused a maximum of 6 to 10 feet of right-lateral offset along about 30 miles of rupture. Rarely is the surface rupture for large earthquakes expressed as a single, clear break, and in this case the rupture along part of its length is unusually broadly distributed. Aftershock forecasts were released for both the M6.4 and M7.1 events. These forecasts were of use to the Navy and the public in general. The USGS ShakeAlert early warning system successfully issued alerts following both large events and the publicly available ShakeAlertLA, a cell-phone application, operated as intended. An alert was not issued for Los Angeles County because the level of shaking predicted for the county did not exceed a threshold set by local officials and was not expected to be damaging.

Studies of the Anchorage, Alaska, Earthquake (USGS)

The USGS responded to a M7.1 earthquake that rocked Anchorage, Alaska and the surrounding region. The November 30, 2018 Anchorage earthquake caused widespread damage to Anchorage and to the Matanuska-Susitna Valley to the north. This earthquake occurred in the Alaska-Aleutian subduction zone, on a fault within the subducting Pacific slab rather than on the shallower boundary between the Pacific and North America plates, similar in setting to the damaging M6.8 Nisqually earthquake near Seattle in February 2001. A few days after this event, USGS as the NEHRP post-earthquake lead agency called a Program phone meeting to discuss the event and the need for a

NEHRP response. The decision was made to implement part of the process defined in the USGS procedures found in USGS Circular 1242, including holding a workshop within one year of the event.

In the immediate aftermath of the earthquake, USGS geologists and engineers mobilized to conduct field reconnaissance, coordinating their activities with state and university colleagues, including Alaskan state scientists and emergency managers, and academic research teams supported by NSF. Teams surveyed landslide and liquefaction occurrence in the region, collected structural monitoring data from buildings, and deployed a temporary network to study basin effects. Situational awareness during response was aided by USGS post-earthquake products including estimates of the extent of landsliding and liquefaction, and a forecast of aftershock occurrence.

The USGS and NSF joined NIST, FEMA, EERI, and the Alaska Earthquake Center in hosting a symposium in Anchorage in September 2019. During that symposium, scientists, emergency responders, utility operators, and state and local officials presented and discussed the response and recovery actions that worked well, as well as those that could be improved. Also presented and discussed during the symposium were the results of scientific studies that will increase understanding of earthquake hazards and consequences in Alaska and how best to plan for, respond to, and recover from future large earthquakes. The scientific results will be presented in papers in a special section of Seismological Research Letters published by the Seismological Society of America in the near future.

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

This strategic goal directly supports the congressionally-defined NEHRP activity, "Develop effective measures for earthquake hazards reduction."[21] NEHRP activities under Goal B are designed to develop practical and cost-effective methods and measures for earthquake risk assessment and mitigation that build upon the research results obtained under Goal A. Representative agency accomplishments and activities under this goal in FY 2018-19 are presented below.

Technical Design Guidelines (FEMA)

In FY 2018-19, FEMA completed several new technical design guidelines, many of which present new state-of-the-art information that has the potential to significantly reduce future earthquake losses. These publications[22] include:

- *Seismic Performance Assessment and Design of Buildings: Volumes 1-7* (FEMA P-58, December 2018)[23]: This fifteen-year effort has resulted in the development of a methodology to assess seismic performance of individual buildings that properly accounts for uncertainty in our ability to accurately predict response and communicates performance in ways that better relate to the decision-making needs of stakeholders. The final products together describe the resulting methodology, as well as the development of basic building information, response

[21] 42 U.S.C. § 7704(a)(2)(A).

[22] FEMA Building Science provides publications and guidance so that communities can become stronger and better able to withstand the harsh effects of these seismic events. Visit https://www.fema.gov/emergency-managers/risk-management/building-science/earthquakes?combine=&page=4.

[23] All FEMA P-58 volumes are available to download at https://femap58.atcouncil.org/reports.

quantities, fragilities, and consequence data used as inputs to the methodology. To allow practical implementation of the methodology, work included the collection of fragility and consequence data for most common structural systems and building occupancies, and the development of an electronic Performance Assessment Calculation Tool for performing the probabilistic computations and accumulation of losses.

- *Vulnerability-Based Seismic Assessment and Retrofit of One- and Two-Family Dwellings* (FEMA P-1100, October 2019): The purpose of this pre-standard is to provide methodologies to identify and retrofit specific known vulnerabilities in wood light-frame dwellings. The publication's assessment and retrofit provisions are based on the best available seismic numerical modeling and engineering practices to develop assessment methods, prescriptive alternatives, and engineering provisions criteria to best achieve targeted performance objectives.
- *Example Application Guide for ASCE/SEI 41-13 Seismic Evaluation and Retrofit of Existing Buildings; with Additional Commentary for ASCE/SEI 41-17* (FEMA P-2006, June 2018): This publication provides guidance on the interpretation and the use of ASCE/SEI 41-13 through a set of examples that address key selected topics. The topics are effectively organized and presented such that information is easy to find. Commentary accompanies the examples to provide context, rationale, and advice, and includes discussion of revisions to the standard made in ASCE/SEI 41-17. The intended audience for this Guide is both practicing engineers and building officials who have limited or no experience with ASCE/SEI 41 or engineers and building officials who have used these documents in the past and have specific questions.
- *Seismic Evaluation of Older Concrete Buildings for Collapse Potential* (FEMA P-2018, December 2018): This report provides a simplified methodology for evaluating collapse resistance using simplified estimates of drift demand. The calculations have been intentionally simplified; however, the underlying criteria are based on probabilistic concepts and structural reliability. The project included testing of the methodology by practicing engineers in several trial evaluations.
- *Guidelines for Design of Structures for Vertical Evacuation from Tsunamis,* Third Edition (FEMA P-646, August 2019): This guidance document provides information for the planning and design of tsunami vertical evacuation structures, including guidance on determining the hazard, options for tsunami vertical evacuation structures, guidance on siting, spacing, sizing, and elevation considerations, and structural design concepts and other considerations. The Third Edition points to Chapter 6 Tsunamis of ASCE/SEI 7-16 for design provisions and removes duplicative material. It also brings in operational material originally published in FEMA P-646A.
- *Assessing Seismic Performance of Buildings with Configuration Irregularities - Calibrating Current Standards and Practices* (FEMA P-2012, September 2018): This report evaluates current building code triggers, the influence of structural irregularities on seismic building performance, and provides design guidance and assessment of ASCE/SEI 7-16 requirements. Most buildings in the U.S. have some irregularities, which are known to influence building seismic performance. ASCE/SEI 7-16 imposes restrictions and special requirements on configuration irregularities in high seismic regions, the guidance and recommendations of this report help to simplify and improve relevant code requirements and design practices. The objective of this project was to inform and improve U.S. codes and standards so that structures with configuration irregularities have a level of safety against collapse in an earthquake that is comparable to that for regular structures.

Guidelines and Tools for Use in Engineering Practice (NIST)

During FY 2018 and 2019, NIST sustained its core NEHRP mission of carrying out research and development to improve community resilience through building codes and standards and practices for structures and lifelines. This included advancing building codes and standards, as well as engineering practice, for structures and lifeline infrastructure in an effort to mitigate the risks posed to the built environment and society-at-large from earthquakes. Ongoing and initiated research activities at NIST focused on increasing advancement and implementation of performance-based seismic engineering procedures for new and existing buildings.
NIST began a significant effort to strengthen its capabilities to conduct structural component testing at NIST by refurbishing laboratory space and equipment. The investment in upgrading the Performance-based Engineering Research for Multi-hazards (PERFORM) Structural Testing Laboratory will mean that more testing will be able to be conducted internally at NIST, resulting in cost and schedule savings over using outside laboratories. Large scale or specialized testing may still require outside laboratories.

Nearly every earthquake investigation reveals damages to nonstructural components (e.g., HVAC equipment, ceiling tile assemblies, facade), driving repair costs and downtime. To align with research efforts focused on structural components, NIST published a Government Contractor Report (GCR)[24] 18-917-43: *Recommendations for Improved Seismic Performance of Nonstructural Components* (**https://nvlpubs.nist.gov/nistpubs/gcr/2018/NIST.GCR.18-917-43.pdf**). This document will help spearhead research activities focused on the performance of nonstructural components during an earthquake.

Based on the observations of building performance during the 2010 Canterbury and 2011 Christchurch earthquakes in New Zealand as well as the 2010 Chile earthquake, NIST continued its project to assess and benchmark U.S. building codes and engineering standards. These earthquakes represent significant events where buildings designed to recent codes similar to those found in the U.S. were shaken. In the case of Chile, a number of important issues have been identified such as slender wall design, that continue to be of research interest. Further, NIST continued to investigate the usage of high-strength materials for concrete components and to evaluate methods and algorithms to measure the analytical collapse resistance of buildings.

NIST initiated a project investigating the seismic performance of wind-load governed steel buildings located in the Central and Eastern U.S. (CEUS). The goal of this project is to improve the resilience of these buildings by identifying the seismic risks and then determine if there can be a reduction in the life-cycle construction cost by developing more efficient seismic resistance. NIST is working with the Applied Technology Council (ATC) to design sixteen archetype buildings located in the CEUS for this project. These buildings are designed twice: once using mid-1980s era building codes and design practices and another using the 2018 edition of the International Building Code (IBC), the primary building code used in the U.S. today. The intent is to assess how the building performance has changed from the 1980's codes to the 2018 IBC.

[24] NIST Government Contractor Report (GCR) 18-917-43 was prepared by a third party (Applied Technology Council) through a formal NIST government contract.

NIST sent an internal team of earthquake experts to evaluate the consequences from the November 30, 2018 M7.1 earthquake near Anchorage, Alaska. The team spent a week in the region evaluating building performance, impacts to society, and emergency operations including risk communication to the public. An NSF-funded research team worked in coordination with the NIST researchers, collecting data relevant to the performance of retrofit buildings. Data acquired is helping NIST address programmatic efforts evaluating existing strategies to systematically characterize lessons learned from earthquakes to support improvements in earthquake resilience.

NIST funded and managed five grants in FY 2017 which continued into FY 2018-19. In addition, NIST funded several additional grantees in FY 2018-19 through the Disaster Resilience Research Grants Program, see Appendix A.3. Each of these grants represents research that is a substantial step toward creating a more disaster resilient nation.

Earthquake Early Warning (ShakeAlert) Implementation (USGS)

In FY 2018-19, the USGS and partners continued to develop and implement the ShakeAlert EEW system as a new product of the USGS ANSS in the three west coast states (CA, OR, and WA). The first rollout phase of the ShakeAlert system began in October 2018, with earthquake alerting to an expanding number of institutional users on the West Coast, including emergency responders, schools, utilities, rail systems, and private companies. The USGS alerts go directly to institutional partners; some of those users are licensed to provide ShakeAlert-driven products and services via software and applications that they develop. In January 2019, the Los Angeles City Mayor released to the public a mobile application called ShakeAlertLA that L.A. residents can use to receive USGS ShakeAlerts. As of the end of FY 2019 the planned network of 1,675 seismic sensors was 63% complete in California and 51% complete in Washington and Oregon. Funding to deploy 400 of the remaining 700 sensors needed was committed from state and federal sources.

Revision of the National Seismic Hazard Model (USGS)

During FY 2018-19, USGS updated its NSHM for the lower-48 states, and delivered the revised model to engineering groups responsible for updating the IBC. The model had last been updated in calendar year 2014. Revision of the NSHM is necessary to incorporate recent scientific advances in several key areas such as:

- new median ground motion models, new estimates of their epistemic uncertainties and aleatory variabilities, and new soil amplification factors for the CEUS,
- amplification of long-period ground motions in deep sedimentary basins in the Los Angeles, San Francisco, Seattle, and Salt Lake City areas, and
- an updated seismicity catalog, which includes new earthquakes that occurred between calendar years 2012 and 2017.

The model was calculated using an improved computer code and with improved implementation details.

Results showed increased ground shaking probability in many (but not all) locations across the CEUS, as well as near the four aforementioned urban areas in the western U.S. Future building code updates that incorporate these latest ground motion estimates will improve the resilience of structures across the nation. A report describing the latest model was published in a peer-reviewed journal[25] early in FY 2020.

[25] See https://journals.sagepub.com/doi/full/10.1177/8755293019878199.

A new seismic hazard model is being developed by USGS for the Hawaiian Islands seismic region to address the unique challenges posed by the superposition of the tectonic systems together with significant volcanic hazards. A workshop was held at the University of Hawaii-Manoa on September 18, 2019 to debut work completed to date.

3.3 Goal C: Improve the Earthquake Resilience of Communities Nationwide

This strategic goal directly supports the congressionally-defined NEHRP program activity, "Promote the adoption of earthquake hazards reduction measures by Federal, State, and local governments, national standards and model code organizations, architects and engineers, building owners, and others with a role in planning and constructing buildings, structures, and lifelines."[26] Through activities supported under Goal C, NEHRP agencies work to apply research results developed under Goal A and risk-reduction methodologies developed under Goal B to practical measures increasing public safety and reducing losses in future earthquakes. Work under this goal includes the monitoring and reporting of seismic activity worldwide. Representative agency accomplishments and activities under this goal in FY 2018-19 are presented below.

State Assistance Grants for Earthquake Preparedness (FEMA)

FEMA managed the State Assistance Grant Program reducing the risks to life and property from future earthquakes in the U.S. through the establishment and maintenance of an effective earthquake hazards reduction program. The FY 2018 State Assistance Grant Program provided $3,630,900.00 to states and local communities to increase and enhance the effective implementation of earthquake risk reduction. In FY 2018, prior to the program reauthorization, the Administrator of FEMA was required to impose the 50% cash match requirement included in the legislation for participating states. The FY 2019 State Assistance Program slightly increased this amount to $3,680,900.00 to states and local communities to increase and enhance the effective implementation of earthquake risk reduction. In FY 2019, Congress replaced the 50% cash match requirement with a 25% cost share requirement that permitted the use of in-kind contributions.

By FEMA making this funding available, states and local communities were able to develop seismic mitigation plans; prepare inventories and conduct seismic safety inspections of critical structures and lifelines; update building codes, zoning codes, and ordinances to enhance seismic safety; increase earthquake awareness and education; encourage the development of multi-state groups that support local earthquake safety and the other eligible program activities; and participate in earthquake exercises that substantially benefit earthquake mitigation efforts. The outcomes of this state assistance grant program were significant as they increased knowledge of earthquake hazard and risks. Mitigation actions have also been taken to support state and local community resilience.

Promoting Earthquake Safety and Awareness Nationwide (FEMA)

Nationwide activities in FY 2018-19 included the annual National Earthquake Program Managers Meeting, the annual Great ShakeOut event, and nationwide training provided through the FEMA National Earthquake Technical Assistance Program (NETAP). In FY 2018, 39 in-person trainings with 1,749 participants were hosted in 14 states/territories and 4 national webinars had a total of 4,242 attendees. In FY 2019, 55 in-person trainings with 2,123 participants were hosted in 12 states/territories and 3 national webinars had a total of 2,413 attendees.

[26] 42 U.S.C. § 7704(a)(2)(B).

Support Improved Building Codes (FEMA)

FEMA participated in the 2021 update cycle of the IBC, International Existing Building Code, International Residential Code and International Performance Code. In FY 2019, FEMA's Seismic Code Support Committee (SCSC), which is managed under contract by the ATC, submitted a total of 12 code change proposals, all of which were approved. FEMA's SCSC was involved in the submittal of another 29 code change proposals but they were submitted under the author's name as FEMA staff had been furloughed and they were unable to approve the changes. All but one of those code change proposals was approved. At the International Code Council Committee Action Hearings, the SCSC also offered testimony on another 90 other code change proposals, either in support or opposition, and were successful almost 90 percent of the time. In FY 2018, FEMA's SCSC successfully revised the International Mechanical Code and the International Plumbing Code to strengthen and expand the references back to the seismic provisions in the IBC.

U.S. 11th National Conference on Earthquake Engineering (FEMA and NIST)

From June 25-29, 2018, NEHRP agencies participated in the 11th National Conference on Earthquake Engineering (11NCEE), which is held once every four years and hosted by EERI. FEMA staff presented a paper entitled "*Improving Building Seismic Performance and Community Resilience*". In addition, Michael Mahoney, Senior Geophysicist at FEMA, received the earthquake community's top lifetime achievement award, the Alfred E. Alquist Special Recognition Medal. This award is presented to an individual "that has made substantial contributions to the field of seismic safety and earthquake risk reduction, having directly affected the seismic safety of the general population. A significant contribution to the public good is the primary selection criterion."

Papers presented at the 11NCEE conference by the NIST Earthquake Engineering Group and the Applied Economics Office can be viewed at https://www.eeri.org/2018/09/11ncee-papers-presentations-view-online/.

The NIST Engineering Laboratory Director, Dr. Howard Harary, and the NIST NEHRP Director, Dr. Steven McCabe, met with the EERI Board of Directors to discuss NEHRP and the program direction. A productive discussion of NEHRP resulted in identifying key areas of cooperation. including continuing active participation by NIST with EERI at conferences, meetings and workshops. NIST engineers and social scientists are engaged in a number of EERI committees and are participating on planning committees for future events.

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

During FY 2018-19, NIST sustained its support for the development of national building codes and engineering standards in an effort to mitigate the risks posed to the built environment and society-at-large from earthquakes. NIST provided technical leadership and expertise to SDOs to advance ASCE 7: *Minimum Design Loads and Associated Criteria for Buildings and Other Structures* and ASCE 41: *Seismic Rehabilitation of Existing Buildings*, while further providing management leadership to the development of new engineering standards, ACI 369: *Guide for Seismic Rehabilitation of Existing Concrete Frame Buildings and Commentary* and AISC 342: *Seismic Provisions for Evaluation and Retrofit of Existing Structural Steel Buildings*, which focus on assessment and retrofit of concrete and steel structural building components, respectively. ACI 318H: Seismic Subcommittee of the Building Code for Structural Concrete, the Building Seismic Safety Council to support work in developing the next

edition of the NEHRP Recommended Provisions, AISI S400-15 North American Standard for Seismic Design of Cold-Formed Steel Structural Systems.

In accordance with Executive Order (EO) 13717, NIST started work on a major update to *Standards of Seismic Safety for Existing Federally Owned and Leased Buildings* for the Interagency Committee on Seismic Safety in Construction (ICSSC). Additionally, NIST prepared a report summarizing federal agency compliance with EO 13717 based on information provided by other federal agencies. EO 13717 is summarized in Appendix B.

Immediate Occupancy of Buildings Study (NIST)

In the FY 2017 final funding package, the Senate assigned NIST the task of developing a report to improve the performance of residential and commercial buildings subjected to natural hazards.

The objective of this effort was to develop a report that identifies: (a) fundamental and applied research needs, and (b) implementation actions to support an "immediate occupancy" design objective. An immediate occupancy performance objective would require design criteria that preserves building integrity and meets a higher level of functionality, in addition to protecting lives. A steering committee of 12 national leaders in resilience of the built environment and natural hazards was assembled by the Science and Technology Policy Institute (STPI), under contract with NIST. The committee was tasked with working with NIST staff and STPI in developing report content for review at a national-level workshop. The workshop was held on January 16-17, 2018 and attended by 100 experts from around the country. A significant challenge in this work was to include appropriate level of detail for relevance across all natural hazards. The efforts of the committee and input gathered during the workshop were used to develop the final report to Congress which was published in August 2018 as NIST SP-1224, *Research Needs to Support Immediate Occupancy Building Performance Following Natural Hazard Events*.

Natural Hazards Center (NSF)

During FY 2018-19, NSF supported 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 (Natural Hazards Observer and Disaster Research); and co-editing the ASCE journal, the Natural Hazards Review. The NHC also organized and hosted three annual workshops; provided library and information services; supported post-disaster, rapid response research; and communicated with the media and the general public concerning disaster risk reduction. During July 8-11, 2018 and July 14-18, 2019, the NHC held its 43rd and 44th, respectively, Annual Natural Hazards Research and Applications Workshop in Broomfield, CO.

Natural Hazards Engineering Research Infrastructure (NSF)

The NSF supported the NHERI Network Coordination Office (NCO) at Purdue University which serves as the hub for NHERI multi-hazards research, coordinating work at the various NHERI experimental facilities, forging national and international partnerships, and organizing education and outreach efforts. The NHERI NCO organized a Research Experiences for Undergraduates (REU) program during the summers of FY 2018 (27 undergraduate students) and FY 2019 (31 undergraduate students), and held a Summer Institute three-day workshop for K-12 educators, engineers, researchers, and early-career faculty, June 4-6, 2018 and June 5-7, 2019.

Student Support and Training (NSF)

The SCEC that is supported jointly by NSF and USGS supports student summer internships as well as student involvement in research into different aspects of earthquake hazards in Southern California. Research Experience for Undergraduates at the Incorporated Research Institutions for Seismology (IRIS) member institutions as well as many of the research awards supported in NSF Engineering that support the NEHRP program include the training of undergraduate and graduate students. Most research awards in NSF Geosciences that support the NEHRP program support the training of students and mentoring of postdoctoral fellows. Several Earth science postdoctoral fellowships awarded by NSF support NEHRP program goals.

Eastern San Francisco Bay Large Earthquake Scenario and Impacts (USGS)

In FY 2019, USGS rolled out the "Haywired" earthquake scenario, which examines a hypothetical earthquake (mainshock) with a M7 on the Hayward Fault in the east bay part of California's San Francisco Bay area. Most economic, cultural, and personal elements of society have grown entwined with the internet since the last time California experienced a large urban earthquake. Questions addressed by the scenario include: What will happen to an internet-dependent society when a large earthquake occurs? How do tangible lifelines—roads, power, water, communication, etc.—interact in damage and restoration, and how do they interact with the online world of commerce, social media, and news? How will aftershocks affect recovery? To answer these questions, the USGS, in partnership with numerous state and local agencies, groups, and subject matter experts, built on past studies of a Hayward Fault earthquake and previous scenario development procedures to advance risk analysis and inform disaster planning in terms of preparedness, response, and recovery. The Haywired scenario was rolled out with critical infrastructure partners in Fremont and a media event and Lawson lecture in the Berkeley Stadium on April 18, 2018, anniversary of the devastating M7.8 1906 San Francisco earthquake. Details of the scenario earthquake, its engineering impacts, and its societal implications were published in a three-volume USGS Report[27].

Routine Issuance of Aftershock Forecasts (USGS)

Beginning in September 2018, the USGS began issuing timely aftershock forecasts following potentially damaging earthquakes within the U.S. and its territories. Forecasts are posted to the USGS web site following earthquakes of M5 or larger, and other domestic earthquakes of particular interest or impact. A broad variety of user groups desire authoritative earthquake forecasts to provide situational awareness and to support decision-making, especially during felt earthquake sequences. Users include emergency managers, policy and decision makers, building and civil engineers, first-responders including urban search and rescue teams, the media, and the general public. USGS also developed the ability to provide aftershock forecasts following significant global earthquakes when called upon by other U.S. government agencies or international partners.

Timely Estimates of Earthquake Triggered Landslides and Liquefaction (USGS)

In September 2018, the USGS began issuing rapid estimates of the extent and importance of potential landslides and liquefaction following significant earthquakes worldwide. Earthquake-triggered landslides and liquefaction, collectively referred to as ground failure, can be a significant contributor to earthquake losses. The USGS Ground Failure earthquake product provides near-real-time spatial estimates of earthquake-triggered landslide and liquefaction hazard following significant

[27] See https://pubs.er.usgs.gov/publication/sir20175013.

earthquakes. It takes time for first responders and experts to survey the actual damage in the area, so the product, which includes maps and estimates of the number of people in affected areas, supports rapid decisions on where to focus attention and response planning. This new product was successfully deployed with other widely used USGS post-earthquake products including ShakeMap, ShakeCast, and PAGER, to provide situational awareness following the Anchorage (M7.1) and Ridgecrest (M7.1) earthquakes.

USGS Participation in a National Earthquake Response Exercise (USGS)

In FY 2019, the USGS contributed to and participated in the large FEMA exercise "Shaken Fury" and related exercises involving many state and federal agencies. The exercise, one of the largest ever for FEMA, simulated an emergency management response to a large (M7.7) earthquake on the New Madrid Seismic Zone, primarily in parts of Arkansas, Missouri and Tennessee but also involving neighboring states. USGS involvement consisted of advising on the earthquake scenario, providing USGS products for the simulation (ShakeMap, alerts, aftershock forecasts), providing numerous briefings to the emergency management community, and providing subject-matter experts in several emergency operations centers. The USGS and the Department of the Interior used the exercise to review and revise their plans for responding to a large earthquake.

Section 4 – Other NEHRP Statutory Activities

4.1 NEHRP Lead Agency Activities (NIST)

NEHRP Office

The NEHRP Office at NIST, which supports NIST's roles and responsibilities as lead agency of NEHRP, continued to provide several statutory program management, coordination, and oversight functions.[28]

During FY 2018-19, the Interagency Coordinating Committee met face-to-face once on August 7, 2019. The ACEHR met face-to-face four times and held one virtual meeting. Additionally, NIST manages the working-level Program Coordination Working Group (PCWG), which is comprised of leaders and managers within OSTP and the four NEHRP agencies who sit at levels within their respective organizations to facilitate the day-to-day operations of their NEHRP activities, and who facilitate interagency communication and coordination. The PCWG met face-to-face eight times and four times by teleconference.

The NIST NEHRP Office continued to provide program coordination. The office organized and conducted the ACEHR and PCWG meetings and maintained the NEHRP website. This website provides information on NEHRP management efforts and products, as well as links to the four Program agencies where further information on earthquake research results, current seismic activity, seismic hazard and risk, and earthquake mitigation practices can be found.

The lead agency Program Office also fulfills all required ACEHR reporting functions for NEHRP including notification of public meetings, documentation of meetings and dissemination of appropriate notifications and reports. Records of these activities, access to ACEHR meeting materials, and additional details can be found on the NEHRP website.[29]

Interagency Coordinating Committee Responses to ACEHR Recommendations

During the August 7, 2019 Interagency Coordinating Committee meeting, the draft outline for updating the NEHRP Strategic Plan was endorsed. The ACEHR provided several observations and recommendations regarding NEHRP activities to the NIST Director, as the Interagency Coordinating Committee Chair, in FY 2019. The ACEHR emphasized that each of the NEHRP agencies brings important expertise, knowledge, and technologies to the table. Keeping agencies aware of their activities, coordinating their efforts through frequent communication, collaborating on new and innovative programs, and integrating to ensure both efficiency and effectiveness enables the synergy needed to achieve progress toward the goal of community resilience. Regular meetings of the Interagency Coordinating Committee, which resumed in August 2019, were highlighted by ACEHR as an essential means for the agencies to collaborate on critical issues in a direct and coordinated fashion. Planned NEHRP activities were endorsed by the ACEHR, but their concern for adequate resourcing of NEHRP remains. Restructured agency reporting focused on the NEHRP

[28] 42 U.S.C. §§ 7704(b)(1) & (b)(5).

[29] See https://www.nehrp.gov/committees/index.htm for additional information on ACEHR.

Strategic Plan and was endorsed by ACEHR. The full text of the recommendations and corresponding responses from the NEHRP agencies are available on the NEHRP website.[30]

4.2 Advanced National Seismic System (USGS)

The ANSS is an effort led by the USGS to support, coordinate, and modernize earthquake monitoring nationwide. The system includes a national scale "backbone" seismic network, the National Earthquake Information Center (NEIC), 12 USGS and partner-operated regional seismic networks, and the National Strong Motion Project (NSMP). Conventional seismic recording systems are not designed to accurately record very strong shaking of the ground and in structures near the epicenter. The NSMP records strong, potentially damaging, earthquake shaking on the ground and in structures. As a result of substantial improvements to data recording and transmission capabilities, station coverage, and methods for rapid analysis, the ANSS now typically reports on domestic earthquakes large enough to be felt by humans within minutes of their occurrence. The NEIC operates 24/7 to determine rapidly and accurately the location and size of all significant earthquakes that occur worldwide and provides situational awareness. Cooperating universities operate regional seismic networks in areas of higher seismic risk to monitor in greater detail and accuracy. 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.

By the end of FY 2019, the number of ANSS-standard stations increased to 3,346, compared to 3,142 in FY 2017. Increases reflect added or upgraded stations on the west coast for EEW and the USGS assuming support for the Central and Eastern Seismic Network (the N4 network). In FY 2018-19, Congress provided funding to support work to address the backlog of ANSS deferred maintenance needs and the adoption and operation of EarthScope stations in Alaska.

4.3 Global Seismographic Network (NSF and USGS)

The GSN consists of 150 stations worldwide. It is jointly supported by the USGS and the NSF and is operated by the USGS in partnership with NSF's SAGE Facility (Seismological Facility for the Advancement of Geoscience). 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 worldwide. GSN data ensure a USGS NEIC capability to characterize all potentially damaging earthquakes. In FY 2018-19, the USGS and SAGE continued to operate the GSN at a high level of data recovery, real-time telemetry performance, and high overall efficiency. The USGS continued to lead a multi-agency effort to install new borehole sensors and perform site improvements. The GSN data quality and availability has been high in recent years, due to modern data recorder and sensor improvements and software to automatically assess the quality of GSN data.

[30] See https://www.nehrp.gov/pdf/ACEHRLetter_Mar18mtg_v6%20FINAL.pdf, https://www.nehrp.gov/pdf/NIST%20response%20to%20March%202018%20ACEHR%20interim%20report.pdf, https://www.nehrp.gov/pdf/ACEHR%20signed%20interim%20letter_May2019.pdf, https://www.nehrp.gov/pdf/NIST%20Response%20to%2005-09-19%20ACEHR%20Interim%20Report%20Ltr.pdf, https://www.nehrp.gov/pdf/September_2019_ReporttotheNISTDirector.pdf, and https://www.nehrp.gov/pdf/NEHRP%20Responses_09-26-19%20ACEHR%20report_FINAL.pdf.

4.4 Functional Recovery Study (FEMA and NIST)

Section 8, *Seismic Standards*, in the Earthquake Hazards Reduction Act, as amended by the NEHRP Reauthorization Act of 2018 (Public Law 115-307), directs NIST and FEMA to form a Committee of Experts to prepare a report on recommended options for improving the built environment and critical infrastructure to reflect performance goals stated in terms of post-earthquake re-occupancy and functional recovery time. FEMA and NIST convened nearly 30 subject-matter experts across technical and review committees to develop and review report content.

4.5 Disaster Recovery Reform Act (DRRA) of 2018 (FEMA)

The Disaster Recovery Reform Act (DRRA) of 2018 was passed by Congress and signed by the President on Oct 5, 2018. The following sections of the DRRA are related to FEMA's normal activities within NEHRP, as described below, including a summary of what FEMA accomplished for each in FY 2019.

- Section 1206 – Eligibility for Code Administration and Enforcement: This provision added authorization for FEMA to provide assistance to state, local, tribal and territorial governments for building code and floodplain management ordinance administration and enforcement. Base and overtime wages for extra hires for enforcement of adopted building codes are now eligible for reimbursement for a period of 180 days post disaster declaration. In FY 2019 FEMA worked to develop a new policy to implement this provision.

- Section 1233 – Additional Hazard Mitigation Activities (Earthquakes): This provision added authorization for FEMA to provide assistance under the Hazard Mitigation Grant Program and the Pre-Disaster Mitigation Grant Program[31] for activities that reduce earthquake risk and support building capability for EEW in areas affected by earthquake hazards. In FY 2019 FEMA began collaborating with the USGS to develop new eligible project types that supported improvements to EEW systems.

- Section 1241 – Post-Disaster Building Safety Assessment: This provision directed FEMA to develop guidance for building experts to use when they assess structures for safety after a disaster. In FY 2019 FEMA worked to develop the requested guidance, as well as guidelines for resource types (job titles) and their requirements for building safety assessment teams under the National Incident Management System.

[31] The Building Resilient Infrastructure and Communities (BRIC) program replaced the Pre-Disaster Mitigation Grant Program in FY 2020. DRRA Section 1234 amended Section 203 of the Stafford Act, authorizing this new program.

Appendix A. NEHRP Agency Supported Activities to Promote Preparedness, Hazard Mitigation Efforts, and Resilience

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

In FY 2018-19, several states focused on hazard analysis activities to better understand their earthquake risk and inform their mitigation investments. Additionally, wide-spread state participation in the Great ShakeOut drills provided an opportunity to practice how to be safer during earthquakes. The Great ShakeOut continues to be a key NEHRP activity conducted by participating states. In FY 18 and FY19 the Great ShakeOut drill had 61.7 million people and 62.5 million people worldwide, respectively. In addition to hazard analysis activities several states conducted trainings to build capacity and competency within each state. For information on all significant FEMA state assistance activities for FY 2018-19, please visit A History of Earthquake Mitigation Activities | FEMA.gov.

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

Every year, the USGS issues a Program Announcement for competitive proposals for grants and cooperative agreements to support research in earthquake hazards, the physics of earthquakes, earthquake occurrence, and earthquake safety policy. In FY 2018-19, the USGS provided substantial support to state institutions, private companies and non-governmental organizations for earthquake monitoring and applied research. This external activity allows the USGS to efficiently accomplish its goals in assessing earthquake hazards, understanding the physics of earthquakes, monitoring earthquake occurrence, and informing earthquake safety policy. The partnerships developed from this support allow the USGS to draw on expertise and capabilities that complement and expand in-house proficiencies.

Funding assistance from the USGS External Grants program was provided to 49 organizations in FY 2018, and to 42 organizations in FY 2019. Grant details and resulting reports for every USGS-funded research project and monitoring effort are posted at https://earthquake.usgs.gov/cfusion/external_grants/research.cfm.

A.3. NIST Disaster Resilience Research Grants

NIST released a Notice of Funding Opportunity on June 28, 2018 to help further its commitment to enhancing the nation's built resilient infrastructure. The Disaster Resilience (DR) Research Grants Program sought applications from eligible applicants to conduct research aimed at advancing the principles of resilience in building design and building codes and standards. In FY 2018-19, NIST awarded[32] more than $6.6 million to study ways buildings can be made more resilient to earthquakes, wind, and fire hazards. Five projects awarded in FY 2017[33] related to earthquake engineering continued through FY 2018-19.

[32] Visit https://www.nist.gov/news-events/news/2019/08/nist-awards-66-million-research-help-structures-better-withstand for a list of grant awardees.
[33] Visit https://www.nist.gov/news-events/news/2017/08/nist-funds-12-projects-make-communities-more-resilient-disasters

Appendix B. Executive Order 13717 Agency Compliance Summary

Executive Order (EO) 13717, *Establishing a Federal Earthquake Risk Management Standard,* was signed on February 2, 2016. The EO establishes a minimum level of seismic safety compliance for new and existing buildings that will be constructed, altered, leased, financed, or regulated by the Federal Government. The primary purpose of this standard is to enhance the seismic resilience of agencies by reducing risk to lives of building occupants and improving the probability of continued performance of buildings essential to agency operations and functions following future earthquakes.

The EO requires that agencies whose activities are covered by the order submit a biennial report to the Director of OMB and the Director of NIST on their progress in implementing the order, commencing two years from the date of the order. NIST, as the NEHRP lead agency and chair of the Interagency Committee on Seismic Safety in Construction, is required by the EO to summarize agency compliance with the order in the biennial NEHRP report to the Congress.

In early 2016, NIST issued a government-wide data collection request to gather responses from all agencies coved by the EO regarding specific requirements in the EO. Subsequently, NIST issued a data call to the agencies that responded to the initial call requesting agency feedback on their efforts to comply with the EO in their policies and procedures for the reporting period of Feb. 2, 2016 through February 1, 2018. A summary of the agency progress reports is contained in NIST Technical Note (TN) 2136-1, *ICSSC Biennial Compliance Report for 2018: Report on Progress Towards Implementation of Executive Order 13717: Establishing a Federal Earthquake Risk Management Standard - Reporting Period: February 2, 2016 to February 1, 2018*.[34]

[34] See https://doi.org/10.6028/NIST.TN.2136-1.

Appendix C. NEHRP Agency Cooperation with Other Relevant Organizations

Applied Technology Council (ATC) supported a significant amount of training through the NETAP program and helped publish the following documents: *FEMA P-1100, Vulnerability-Based Seismic Assessment and Retrofit of One- and Two-Family Dwellings*; *FEMA P-2012, Assessing Seismic Performance of Buildings with Configuration Irregularities: Calibrating Current Standards and Practices*; *FEMA P-2018, Seismic Evaluation of Older Concrete Buildings for Collapse Potential*; *FEMA P-58-1 through 58-7, Seismic Performance Assessment of Buildings*; *FEMA P-646, Guidelines for Design of Structures for Vertical Evacuation from Tsunamis, Third Edition*; and *FEMA P-1024-RA2, South Napa Earthquake Recovery Advisory: Earthquake Strengthening of Cripple Walls in Wood-Frame Dwellings, Second Edition*.

Building Seismic Safety Council (BSSC), under the sponsorship of FEMA and with the participation of NIST and USGS, the BSSC, a branch of the National Institute of Building Sciences, continued managing the development of the *2020 NEHRP Recommended Seismic Provisions.* The BSSC also managed Project 17 and facilitated the coordination of practicing engineers, NIST engineers, and USGS scientists engaged in formulating the rules by which next-generation seismic design value maps will be developed as a basis for structural design. The final report with recommendations was published.

Cascadia Region Earthquake Workgroup (CREW) continued effort on the EEW systems has made tremendous impact for the community and partners. They have increased awareness to first responders, private and critical infrastructure sectors, elected officials, and the general public of the importance of earthquake mitigation and the benefits and opportunities of the upcoming ShakeAlert system they are developing.

Central U.S. Earthquake Consortium (CUSEC), along with FEMA, provided multi-state outreach and awareness to assist states by providing materials, information and shake tables that show potential impacts of earthquakes to buildings. CUSEC held workshops that brought together emergency management and critical infrastructure providers to address potential impacts and recovery issues following a regional catastrophic disaster such as an earthquake occurring in the New Madrid Seismic Zone.

Earthquake Country Alliance (ECA), along with FEMA, leveraged local alliances in Southern California and the Bay Area to develop and promote *Staying Safe Where the Earth Shakes,* a booklet that includes the *Seven Steps to Earthquake Safety,* which are basic guidelines for what to do before, during, and after a damaging earthquake.

Earthquake Engineering Research Institute (EERI), with support from USGS and FEMA, activated a Virtual Clearinghouse for the November 2018 Alaska Earthquake. They conducted six technical webinars that provided an overview of the earthquake impacts and science and engineering impacts of earthquakes.

Federal Alliance for Safe Homes (FLASH) in partnership with FEMA released the latest building code commentary which details the "No Code. No Confidence." consumer research findings and building code insights and scenarios. The "No Code. No Confidence." campaign was designed to increase consumer awareness of the role of building codes and standards, to promote a better understanding of the benefits of codes, and to create market demand for adoption and enforcement of building codes.

Mitigation Framework Leadership Group (MitFLG) wrapped up a long-term project under the 2019 National Mitigation Investment Strategy (NMIS) focused on reducing seismic risk for unreinforced masonry (URM) construction with partners in Utah. In August 2019, FEMA released the NMIS[35] in coordination with MitFLG. The report was developed to help the nation be more intentional about setting resilience and mitigation investment priorities to benefit the whole community. In Utah, it is estimated more than 140,000 URM structures including homes, businesses, schools and houses of worship could be significantly impacted by seismic activity. Due to Utah's URM issues and its dedication to creating a solution, the Wasatch Front URM Risk Reduction Strategy was selected as a pilot project through the NMIS. This project brings together local and national experts to develop a mitigation strategy that highlights key concepts that drive risk reduction outcomes.

Northeast States Emergency Consortium (NESEC) prepared HAZUS Multi-Hazard Earthquake Analyses for Maine and Vermont in support of earthquake hazard awareness and mitigation. They provided *Map Your Risk* assistance to Massachusetts and New Hampshire to help them better understand and quantify their earthquake and related hazard risk.

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

Science for Disaster Reduction (SDR) interagency coordination group promotes interaction across Federal agencies, and between Federal and non-Federal entities, responsible for both producing and consuming science and technology (S&T) for disaster risk reduction. Members share information about new findings, technological advances, identified needs, and ideas for how to improve collaborations and effectiveness. When disasters occur, the SDR facilitates coordination in support of response and conducts debriefings afterward, to ensure that agencies share important lessons and concerns. SDR also serves as the U.S. platform for the United Nation's International Disaster Risk Reduction activities. Representatives of the NEHRP agencies participate in SDR. The forum is a valuable venue for learning from and reaching out to other Federal agencies doing work related to NEHRP goals and objectives.

Subcommittee on Resilience Science and Technology (SRST) is a subcommittee of the Committee on Homeland and National Security of the National Science and Technology Council (NSTC). The SRST provides policy advice to ensure that Federal S&T activities and investments will efficiently and effectively improve national resilience to threats and hazards, both natural and human caused. Most of the NEHRP agencies are represented on the SRST and ensure that NEHRP insights are shared as the subcommittee develops policy for national resilience S&T and that NEHRP activities are consonant with executive policy.

Western States Seismic Policy Council (WSSPC) members reviewed six policy recommendations and made revisions relating to earthquake monitoring networks, EEW systems, mitigation of unreinforced masonry buildings, seismic design and construction of new schools, and the improvement of tsunami public education.

[35] National Mitigation Investment Strategy report https://www.fema.gov/sites/default/files/2020-10/fema_national-mitigation-investment-strategy.pdf

Appendix D. Major Earthquakes in FY 2018 and FY 2019[36]

D.1. Global Seismicity Statistics

Globally there were 14,703 earthquakes with a M4.5 or greater in FY 2018-19. This worldwide activity is more than the 20-year average of 6,441 annually. There were 28 earthquakes worldwide of M7.0 or greater in FY 2018-19, which is higher than the average annual occurrence rate of 14 M7.0 or greater earthquakes per year over the last 40 years.

D.2. Major Domestic Earthquakes

During FY 2018, the largest earthquake in the U.S. was the 2018-01-23 M7.9 Kodiak, Alaska earthquake. The largest earthquakes in the U.S. during FY 2019 were the 2018-11-30 M7.1 Anchorage, Alaska and 2019-07-06 M7.1 Ridgecrest, California earthquakes.

In the contiguous U.S. during FY 2018-19, the most notable activity was the 2019-07-06 M7.1 Ridgecrest, California earthquake. The USGS recorded a total of 2,573 M3.0 or larger earthquakes in the region (1,781 earthquakes in FY 2019 mostly from Ridgecrest aftershocks) compared to 1,198 M3.0 or greater earthquakes in FY 2017.

D.3. Notable Foreign Earthquakes

In FY 2018-19, forty-five international earthquakes caused deaths and/or injuries. The costliest was the 2018-06-16 M5.5 Hirakata, Japan earthquake that killed five people with estimated economic losses of $3.25B. The deadliest earthquake was the 2018-09-28 M7.5 Sulawesi earthquake that killed at least 2,077 people, injured another 4,438, and displaced more than 200,000 people.

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

Appendix E. List of Acronyms and Abbreviations

ACEHR	Advisory Committee on Earthquake Hazards Reduction
ANSS	Advanced National Seismic System
ASCE	American Society of Civil Engineers
ATC	Applied Technology Council
BRIC	(FEMA) Building Resilient Infrastructure and Communities
BSSC	Building Seismic Safety Council
CEUS	Central and Eastern United States
CREW	Cascadia Region Earthquake Workgroup
CSZ	Cascadia subduction zone
CUSEC	Central United States Earthquake Consortium
DRRA	Disaster Recovery Reform Act
ECA	Earthquake Country Alliance
EERI	Earthquake Engineering Research Institute
EEW	Earthquake Early Warning
EHP	(USGS) Earthquake Hazards Program
EO	Executive Order
EOCs	Emergency Operation Centers
FEMA	Federal Emergency Management Agency
FLASH	Federal Alliance for Safe Homes
FY	fiscal year
GCR	Government Contractor Report
GSN	Global Seismographic Network
HAZUS	Hazards U.S.
HQ	headquarters
IO	immediate occupancy
IRIS	Incorporated Research Institutions for Seismology
LBJTMC	Lyndon B. Johnson Tropical Medical Center
LHPOST	large, high performance outdoor shake table
M	magnitude
$M	(dollars) million

MitFLG	Mitigation Framework Leadership Group
NCO	(NSF) Network Coordination Office for NHERI
NEIC	National Earthquake Information Center
NEES	George E. Brown, Jr. Network for Earthquake Engineering Simulation
NEHRP	National Earthquake Hazards Reduction Program
NESEC	Northeast States Emergency Consortium
NETAP	National Earthquake Technical Assistance Program
NHC	Natural Hazards Center
NHERI	(NSF) Natural Hazards Engineering Research Infrastructure
NIST	National Institute of Standards and Technology
NMIS	National Mitigation Investment Strategy
NSF	National Science Foundation
NSHM	National Seismic Hazard Model
NSMP	National Strong Motion Project
NSTC	National Science and Technology Council
OMB	Office of Management and Budget
OSTP	White House Office of Science and Technology Policy
PBSD	performance-based seismic design
PCWG	(NEHRP) Program Coordination Working Group
PERFORM	Performance-based Engineering Research for Multi-hazards
PSA	Public Service Announcement
R&D	research and development
REU	Research Experiences for Undergraduates
RVS	Rapid Visual Screening
S&E	salaries and expenses
S&T	science and technology
SAGE	(NSF) Seismological Facility for the Advancement of Geoscience
SCEC	Southern California Earthquake Center
SCSC	(FEMA) Seismic Code Support Committee
SDO	Standards Development Organization
SEI	Structural Engineering Institute
SDR	Science for Disaster Reduction

SP	(NIST) Special Publication
SRST	Subcommittee on Resilience Science and Technology
STPI	Science and Technology Policy Institute
TN	(NIST) Technical Note
UCERF	Uniform California Earthquake Rupture Forecast
URM	unreinforced masonry
USGS	United States Geological Survey
WSSPC	Western States Seismic Policy Council