**Testimony of**
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**Before the**
**U.S. House of Representatives**
**Committee on Science, Space, and Technology**
**Subcommittee on Research and Technology**

***The National Earthquake Hazards Reduction Program (NEHRP)***

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## INTRODUCTION

Chairman Bucshon, Ranking Member Lipinski and other distinguished members of the Subcommittee; it is my pleasure to be able to testify before you today on the topic of the National Science Foundation's (NSF) activities in earthquake hazards reduction. I am Pramod Khargonekar, Assistant Director for the Directorate for Engineering at the National Science Foundation.

The primary mission of the Foundation is to support fundamental research and education in science, technology, engineering and mathematics. This mission contributes to the national health, prosperity and welfare, and to the national security against such threats as natural hazards, including earthquakes and wind. Although our national security efforts often focus on terrorism, natural hazards are an even greater threat to our security. In 2012, the United States (U.S.) suffered 3,836 earthquakes, of which 32 were of magnitude 5 or greater. The U.S. also experiences over 1,200 tornadoes annually, many resulting in substantial destruction of property and loss of life. Every state has been a recent victim of earthquakes and/or tornadoes. In addition, coastal regions of the nation are subject to the annual season of hurricanes, with devastation such as that caused by Hurricane Sandy in 2012. As you know, the nation is still engaged in the process of recovery from that storm.

NEHRP is a strong and dynamic program at NSF, and we hope to continue to support research, education, and facilities to mitigate the impacts of earthquake hazards. We thank the Subcommittee for considering priorities for reauthorization of the program and appreciate the opportunity to testify today. NSF-supported research in this area is driven by the need for new

scientific and engineering knowledge and effective technologies that can significantly reduce the impacts of hazards to our built environment and our personal safety, as well as substantially reduced costs of emergency and recovery actions.

## THE NSF ROLE IN NEHRP

Pursuant to the Earthquake Hazards Reduction Act (EHRA) of 1977, the National Earthquake Hazards Reduction Program (NEHRP) was established in 1978 and operates as a multi-agency partnership of which NSF is a member. NSF supports a broad range of fundamental research in geosciences, engineering, and social, behavioral and economic sciences relevant to the understanding of the causes of earthquakes, and mitigation of and resilience to their impacts. We support research on the dynamics of earthquakes, plate tectonics and crustal deformation as well as the seismic performance of geotechnical, structural, nonstructural and infrastructure-lifeline systems. This support includes research on social, behavioral and economic phenomena such as risk perception, mitigation decision making, incentive systems related to risk and mitigation, and factors that can promote community resilience. The Foundation also provides support for the education of new scientists and engineers, the integration of research and education, and outreach to professionals and the public.

### Multi-User Facilities

NSF supports three distributed, multi-user, national facilities that support critical fundamental research relevant to NEHRP: the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES), the Geodetic Facilities for the Advancement of Geoscience and EarthScope (GAGE) and the Seismological Facilities for the Advancement of Geoscience and EarthScope (SAGE).

NEES currently provides access to 14 earthquake simulation experimental facilities located in several universities across eight states, with headquarters at Purdue University in West Lafayette, Indiana. The Purdue facility includes the NEEShub, which provides cyberinfrastructure for a data repository, telepresence, simulation tools, collaboration tools and cybersecurity. The NEES facilities include shake tables, large-scale laboratories, geotechnical centrifuges, field testing equipment and a tsunami wave basin. It is very important to note that, in addition to NEES facility funding, the Foundation funds fundamental engineering research using the NEES facilities under an activity referred to as NEES Research (NEESR).

The GAGE and SAGE facilities provide key data, instrumentation, and educational information in support of national goals in basic research and education in the Earth sciences. Of particular relevance to NEHRP, SAGE supports the Global Seismographic Network (GSN), a worldwide array of 153 permanent seismic stations funded by NSF and USGS, with additional support from the Departments of Energy, State, and Defense. GSN provides high-quality digital seismic data for use in a wide range of research and educational activities, and for key international treaty obligations including nuclear verification.

**Funded Research, Centers, and Collaborations**

Continued progress toward the goal of a more earthquake resilient nation is built on a foundation of **fundamental research** into the processes that drive and control earthquakes and into the impacts of earthquakes on the built environment. NSF supports such research through multiple research programs in the Directorate for Engineering and the Directorate for Geosciences. In Engineering, the Hazard Mitigation and Structural Engineering (HMSE) program, Geotechnical Engineering (GTE) program, and Infrastructure Management and Extreme Events (IMEE) programs support a wide range of NEHRP-relevant research. In Geosciences, relevant programs include EarthScope, Geophysics, GeoPRISMS, Marine Geology and Geophysics, Petrology and Geochemistry, and Tectonics.

NSF also supports a variety of **centers and research collaborations** relevant to NEHRP. For example, in partnership with several other Federal agencies, NSF supports the Natural Hazards Center at the University of Colorado, Boulder. The Natural Hazards Center works to reduce losses from all natural hazards, including earthquakes. It does this primarily by strengthening communications among hazards researchers, practitioners, and policy makers. It hosts an annual natural hazards research and applications workshop, issues several relevant publications, and it includes a quick-response research program for social and behavioral scientists to visit sites of recent disasters to gather perishable research data.

Through its research programs, NSF also supports rapid response activities to gather data from disaster sites using its **RAPID (Rapid Response Research) funding mechanism**. In the aftermath of the Darfield and Canterbury, New Zealand, earthquakes in 2010 and 2011 respectively, and the March, 2011, Tohoku, Japan, earthquake, tsunami and the Fukushima nuclear power plant crisis, NSF acted quickly to fund more than 30 RAPID awards, many with collaborators from the affected countries. On August 23, 2011, an earthquake of magnitude 5.8 struck near Mineral, Virginia, significantly affecting the Washington, DC, area. This earthquake was felt by over 30 million people from Georgia to southeastern Canada, and provided an opportunity for the study of the causes and effects of earthquakes in the Eastern United States. NSF funded awards to the Geotechnical Extreme Events Reconnaissance (GEER) Organization at UC Berkeley, Cornell University, Virginia Tech, and Lehigh University to study this earthquake. This rapid-response research found a clear correlation between geotechnical conditions and structural damage. Soil amplification in soft sediments overlying hard rock influenced damage and shaking intensity patterns, as did the underlying geologic structure associated with the Appalachian Mountains and the strike of regional geologic faulting.

The **Southern California Earthquake Center (SCEC)** began in 1991, and continued through 2001 as an NSF Science and Technology Center; since 2001, SCEC has continued with support from both NSF and USGS. SCEC is based at the University of Southern California and unites 13 core university partners and 36 other U.S. universities, private industry, and state and local governments in an integrative and multidisciplinary research and education partnership. SCEC's primary mission is to (a) gather new information about earthquakes in Southern California; (b) integrate this information into a comprehensive and predictive understanding of earthquake phenomena; and (c) communicate this understanding to end-users and the general public in order to increase earthquake awareness and reduce earthquake risk. SCEC has also led

the major ShakeOut earthquake response drills, which had over 20 million participants nationwide in 2013 alone; ShakeOut has been supported by Federal Emergency Management Agency (FEMA), state and local governments, and private organizations.

**EarthScope** is an Earth science program to explore the continental structure of North America and provides a framework for broad integrated studies, including research on fault properties and the earthquake process. EarthScope was initiated in 2003, in partnership with the USGS and NASA. The last increment for support of the EarthScope facility (via SAGE and GAGE) will be allocated at the end of FY 2017, providing for operation and maintenance of seismic and geodetic observations through September 2018. The EarthScope Facility is a multi-purpose array of instruments that greatly expands the observational capabilities of the Earth sciences and permits us to advance our understanding of the structure, evolution, and dynamics of North America. The EarthScope Facility comprises the Plate Boundary Observatory (PBO) that monitors Earth deformation with GPS, strainmeters, and other geodetic systems; the San Andreas Fault Observatory at Depth (SAFOD) that defines the conditions and physics of an active plate boundary fault at depth, and USArray, a continental-scale network that maps Earth's interior in three dimensions using seismic and magnetotelluric systems. EarthScope research and instrumentation provides unprecedented accessibility to rich data sets. Scientists using EarthScope data are developing a comprehensive understanding of the structure, dynamics, and evolution of North America that goes beyond the insights possible without this multidisciplinary and integrated capability.

Selected achievements of NSF-funded grantees:

- NSF-funded researchers have discovered how to make underground water lines that bend and move rather than snap and rupture in an earthquake. The team, led by Cornell University, found that medium and high-density polyethylene pipelines remain intact even when the Earth liquefies and shifts. Based on positive laboratory tests and successful real-world performance in Christchurch, the city of Los Angeles is now installing these pipelines in the Elizabeth Tunnel, which provides half the city's water supply[1].

- Recognizing the apparent imbalance between ports' economic value and seismic vulnerability, in 2005 NSF supported a research project to a consortium of universities and firms led by the Georgia Institute of Technology. Project researchers found that a majority of the ports located in areas of high seismic hazard had either no—or only informal—seismic risk mitigation plans. The project team developed a new approach for assessing and managing seismic risk in container ports, an approach more useful to the facility stakeholders. To develop the framework, the team conducted interdisciplinary research that utilized the full range of resources that were uniquely available through the NSF-supported

[1] http://www.purdue.edu/newsroom/releases/2013/Q1/earthquake-resilience-pipeline-of-innovation-to-keep-water-flowing-to-los-angeles.html

NEES facilities, including state-of-the-art computer simulation tools, shake tables, centrifuges, and field testing equipment[2].

- Researchers conducted a series of tests using the large outdoor shake table at the University of California, San Diego (part of NEES) to learn how to help high-value buildings, such as hospitals and data centers, remain operational after earthquakes[3]. These were the first shake table tests of entire nonstructural systems at full scale, and they also examined the interaction between structural and nonstructural systems. This research project (led by UCSD and supported by NSF, FEMA, and industry) is expected to improve modeling tools, educational programs, and standards and practices in the fields of performance-based building design and construction; design and installation practices, building codes, and standards related to nonstructural components and systems.

## MULTI-AGENCY COORDINATION

The NEHRP agencies work closely to coordinate efforts. Beyond the earthquake research NSF funds by itself, we also co-fund joint projects with the other NEHRP agencies (examples previously mentioned include SCEC with USGS; Natural Hazards Center with FEMA and USGS). In 2013, NSF and USGS began a cooperative project to convert to long-term operations selected former Transportable Array seismic stations in the central and eastern United States, working in collaboration with the National Research Council, Department of Energy, and interested state governments and university partners. This Central and Eastern United States Seismic Network (CEUSN) project will convert 150-200 seismic stations to enhance regional seismic monitoring, improve oversight of critical facilities, expand our understanding of seismic hazard in the CEUSN, improve detection and expand understanding of earthquakes induced by the injection of wastewater and other fluids, and provide additional data for Earth science research. NSF is supporting conversion and initial operations of the stations; if funding permits, USGS will support long-term operations and integration of these stations into the USGS Advanced National Seismic System.

NSF-funded research is frequently utilized by other agencies to further applied research and produce reports on the seismic performance of buildings and other structures[4]. The NSF-funded NEES infrastructure has also been utilized by NIST to support the development a prototype post-disaster database[5]. Beyond other avenues for publication of research, many results are also disseminated through the NEHRP "Seismic Wave" publication, which highlights success stories of the program[6].

The day-to-day coordination of NEHRP takes place through a number of formal and informal mechanisms. NSF actively contributes to the NEHRP Program Coordination Working

[2] http://www.nehrp.gov/pdf/SeismicWavesMay13.pdf
[3] http://bncs.ucsd.edu/index.html
[4] http://www.fema.gov/media-library-data/20130726-1730-25045-1580/femap_750.pdf
[5] http://wtcdata.nist.gov/index2.htm
[6] http://www.nehrp.gov/library/success.htm

Group, and the NSF Director participates on the Interagency Coordinating Committee (ICC). To engage directly with the NEHRP community, NSF staff also brief the NEHRP Advisory Committee for Earthquake Hazards Reduction (ACEHR) and responds to its recommendations for NSF.

Finally, post-earthquake investigation activities are coordinated across the NEHRP agencies, with USGS leading these efforts. NSF-supported RAPID awardees and other NSF-supported post-earthquake investigators participate on the NEHRP post-earthquake teleconferences to share deployment information and get updates on aftershock activity. For example, NSF worked with NEHRP partner agencies to coordinate responses to major earthquakes such as the 2008 Wenchuan, China earthquake, 2010 Haiti earthquake, 2010/2011 New Zealand earthquakes, and the 2011 Japan earthquake.

## FUTURE DIRECTIONS

NSF appreciates the Congressional support for NEHRP and that the Committee is considering reauthorizing the program. As you consider your legislation, I would like to highlight some specific areas of importance to NSF.

### NEES

NSF has supported NEES operations and the complementary NEES Research program since FY 2005. NEES *operations* are currently supported through an award to Purdue University covering the fiscal years 2010-2014. In anticipation of the expiration of the current NEES operational award in September 2014, in 2010 NSF began a process of external evaluation and planning for continued investment in earthquake engineering facilities. This planning resulted in a call for greater emphasis on frontier research and computational simulation capabilities for multi-hazards risk and sustainability for civil infrastructure, a strong emphasis on continued provision of cyberinfrastructure and data sharing, and closer ties among research efforts supported across relevant Engineering research programs. These plans were shared broadly with the research community in 2012 via a Dear Colleague Letter, NSF 12-107.

In accordance with these plans, NSF hosted a competition to support an updated "NEES2" infrastructure for the FY 2015-2019 period under a single umbrella award. The outcome of the subsequent merit review of the proposals was that that no award was made. Following this outcome, NSF began a different programmatic approach to meet our scientific and engineering research goals and to better capitalize on related research programs within NSF and those supported by our Federal agency partners.

This updated strategy maintains our commitment to balance NSF investments in research infrastructure and fundamental research with the following provisions. First, there will be no single umbrella award. Rather, NSF will support multiple separate awards, and it will manage these awards under a program named Natural Hazards Engineering Research Infrastructure (NHERI). NHERI will consist of (1) a single award for a national office to facilitate coordination among the NHERI awardees and community outreach, (2) a single award for cyberinfrastructure

that will enable sharing of data, models, and simulation tools for all research supported by the Directorate for Engineering in the area of natural hazards and civil infrastructure (this award will be supported by a second single award for a simulation center to develop the computational and simulation tools delivered by the cyberinfrastructure platform), and (3) up to seven awards for earthquake and wind engineering experimental facilities.

NHERI will be supported under a single, unified natural hazards research program in the Civil, Mechanical and Manufacturing Innovation Division of the Directorate for Engineering. The program will support earthquake engineering, wind engineering and other natural hazards research. These modifications will allow NSF to more effectively and efficiently support the research and facilities needed to address the multiple hazards faced by our nation every day.

GAGE and SAGE

NSF also plans to support the GAGE and SAGE facilities through FY 2017, and is working closely with USGS and other Federal, State, and university partners to ensure that the facilities continue to provide the critical data required. For example, geodetic data provided through GAGE are being included in nascent earthquake early warning systems under development on the west coast with support from USGS and other Federal agencies and from private foundations. Such systems can provide a few seconds to minutes of warning, which is enough time to take short-term protective actions like stopping trains and heavy equipment, opening fire station doors, pausing delicate surgical procedures, and moving to nearby safer zones. These same data are also being incorporated into the latest generation of the National Seismic Hazard Maps developed by USGS.

**SUMMARY**

Our understanding of earthquakes and other natural hazards has improved greatly over the past forty years, and the benefits of this understanding are clearly evident in the substantial reduction in both fatalities and damage to civil infrastructure. Throughout this period, the National Science Foundation has been at the forefront in supporting research that covers the full breadth of science, engineering and social sciences as they relate to natural hazards. NEHRP is a critical part of this research. Our plan for the future is to continue our leadership role in earthquake research, and to broaden the scope of our activities to include multiple hazards simultaneously. Indeed, our infrastructure is not designed to cope with one or another hazard alone, but rather to cope with the full panoply of potential hazards in a single design. Infrastructure must be hardened against all natural disasters, not just earthquakes. The challenges that remain are substantial, but it is clear that continued research investments to mitigate the impacts of natural hazards will yield returns to society that greatly outweigh the costs.

The National Science Foundation (NSF) selected Dr. Pramod P. Khargonekar to serve as assistant director for the Directorate of Engineering (ENG). In this position, Khargonekar will lead the ENG Directorate with an annual budget of more than $800 million. The ENG Directorate invests in frontier engineering research and education, cultivates an innovation ecosystem, and develops the next-generation of engineers.

Prior to his position at NSF, Khargonekar was the deputy director for technology at the U.S. Department of Energy's Advanced Research Projects Agency-Energy (ARPA-E). He is the Eckis Professor of Electrical and Computer Engineering at the University of Florida, a position he has held since 2001, and one he will retain while at NSF. He served as the dean of the University of Florida's College of Engineering from 2001 to 2009.

"Dr. Khargonekar brings to NSF extensive leadership, creativity and initiative in engineering research," said NSF Director Subra Suresh. "He has helped pioneer interdisciplinary efforts between the biological and engineering research communities and demonstrated a deep appreciation for developing the STEM workforce, which is an NSF priority."

NSF's investments in engineering research and education aim to build and strengthen a national capacity for innovation that can lead, over time, to the creation of new shared wealth and a better quality of life. The ENG Directorate also supports NSF's Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs.

Khargonekar's engineering research encompasses control systems theory and applications, smart grid and renewable energy, semiconductor manufacturing, and modeling and control of neural systems, among other areas. He has received many awards and honors including the IEEE Baker Prize, the American Automatic Control Council's Donald Eckman Award, the Distinguished Alumnus Award from the Indian Institute of Technology, Bombay, and was named a Web of Science Highly Cited Researcher. Khargonekar is a fellow of IEEE. Most recently, he has been a member of NSF's Engineering Advisory Committee, where he provided guidance to ENG on strategic directions.

Khargonekar began his NSF appointment in March 2013.

Credit: *NSF/Sandy Schaeffer Photography*