Testimony of

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The Need for Resilience: Preparing America's Transportation Infrastructure for Climate Change

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Introduction

Chairwoman Sherrill, Ranking Member Norman, and Members of the Subcommittee, I am Jason Averill, Chief of the Materials and Structural Systems Division at the Department of Commerce's National Institute of Standards and Technology (NIST). The NIST laboratory programs work at the frontiers of measurement science to ensure that the U.S. system of measurements is firmly grounded in sound scientific and technical principles. With the unique facilities at the NIST laboratories, we address complex measurement challenges on every scale, from the chemical kinetics of cement hydration, to buildings, and the resilience of whole communities. Thank you for the opportunity to appear before you today to discuss NIST's role in, and programs focused on, resilience of transportation infrastructure.

NIST and Community Resilience

Recent events, including the 2017 U.S. hurricane season and the 2018 wildfire season, remind us that natural, technological, and human-caused hazards take a high toll on communities, and that the impacts can last long after the event. To help address these impacts, NIST manages a multi-faceted Community Resilience Program, a part of our broader disaster resilience work, assisting communities and stakeholders on issues related to buildings, social functions, and the interdependencies of physical infrastructure systems, including the transportation network.

Principal among these efforts is support for science-based resilience planning. Effective planning can improve a community's quality of life, economic well-being, its ability to recover rapidly, and build back better. To support community planning, NIST produced the NIST Community Resilience Planning Guide for Buildings and Infrastructure Systems (Guide),[1] that provides a practical and flexible approach to help all communities improve their resilience by setting priorities and allocating resources to manage risks for their prevailing hazards. Using the Guide can help communities to integrate consistent resilience goals into their comprehensive, economic development, zoning, mitigation, and other local planning activities that impact buildings, public utilities, transportation, and other infrastructure systems.

The Guide's six-step process helps communities to think through and plan for their social and economic needs, their particular hazard risks, and recovery of the built environment by:

- setting performance goals for vital social functions—healthcare, education, and public safety—and supporting buildings and infrastructure systems—transportation, energy, communications, and water and wastewater;
- recognizing that the community's social and economic needs and functions should drive goal-setting for how the built environment performs; and
- providing a comprehensive method to align community priorities and resources with resilience goals.

In addition, the NIST Community Resilience Economic Decision Guide for Buildings and Infrastructure Systems (EDG)[2] provides a standard economic methodology for evaluating

[1] https://www.nist.gov/topics/community-resilience/planning-guide
[2] https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1197.pdf

investment decisions aimed at improving the ability of communities to adapt to, withstand, and quickly recover from disruptive events. The Economic Decision Guide, designed for use in conjunction with the Guide, offers an easy-to-follow approach that describes the costs and benefits for the variety of resilience options that a community may be considering.

The Economic Decision Guide frames the economic decision process by identifying and comparing the present and future streams of costs and benefits of resilience investments to the status-quo. Benefits are quantified through cost savings and damage loss avoidance. Other topics include non-market values, uncertainty, co-benefits related to resilience investments, and positive and negative externalities - costs or benefits that impact a third party - for a given strategy. NIST has also published the "EDGe$" Tool,[3] a powerful, software-based technique for selecting cost-effective, infrastructure-based community resilience projects based on the Economic Decision Guide.

NIST-funded *Center for Risk-Based Community Resilience Planning*

In order to supplement the NIST Community Resilience Research Program, NIST has designated a NIST Center of Excellence devoted to community resilience. The *Center for Risk-Based Community Resilience Planning*[4] (Center) was awarded to a 12-university partnership led by Colorado State University in February 2015.[5] The Center will accelerate the development of system-level models and associated data and databases to support community resilience decision-making. The Center's multi-disciplinary team includes experts in engineering, economics, data and computing, and social sciences. Their research will support development of metrics and tools that will help decision-makers decide how to best invest resources intended to lessen the impact of hazards on buildings and infrastructure systems, and how to recover rapidly and minimize community disruption.

The centerpiece of the Center's effort is IN-CORE—the Interdependent Networked-Community Resilience Modeling Environment. Built on an open-source platform, the computer model and associated software and databases will incorporate a risk-based approach to decision-making that will provide a quantitative and science-based approach to community resilience assessment and support a business case for enhancing disaster resilience at the community level.[6]

[3] https://www.nist.gov/news-events/news/2018/01/new-nist-edge-tool-can-help-communities-select-cost-effective-resilience

[4] https://www.nist.gov/coe/community-resilience-center-excellence

[5] The partners in the Center of Excellence include Colorado State University, University of Illinois at Champagne Urbana, University of Oklahoma, Rice University, Oregon State University, Texas A&M University, University of South Alabama, University of Colorado Boulder, California Polytechnic at Pomona, University of Washington, University of Kansas, and Iowa State University

[6] More information on the Center can be found at http://resilience.colostate.edu/

Working with U.S. Communities

NIST is committed to working with our federal partners to transfer research results and products to end-users.[7] For example, Nashua, New Hampshire, faces a variety of potential hazards, including riverine flooding. Nashua regularly experiences flooding due to an overwhelmed stormwater infrastructure and impervious cover such as roadways, parking lots, rooftops, and sidewalks.

Partnering with NIST, the Environmental Protection Agency, and using Federal Emergency Management Agency (FEMA) tools, Nashua is developing a proactive and integrated plan that addresses shocks and stressors ranging from natural disasters to adverse socio-economic trends. Through Resilient Nashua, the City is engaging with a broad and diverse set of community stakeholders. Nashua is using the six-step planning process in NIST's Guide to assist in its initiative. Nashua has developed its performance goals and is in the process of using FEMA tools to determine the anticipated performance of its buildings.

Nashua has identified five resilience focus areas: (1) aging infrastructure; (2) climate change and adaptation; (3) services for an increasingly diversified population; (4) resiliency as a culture; and (5) community health. In 2019, the City's resilience planning efforts will culminate in an updated Hazard Mitigation Plan and a first-time Community Resilience Strategy. The document will contain required FEMA hazard mitigation components and also present a strategy for community resilience-oriented preparedness, continuity of operations, and social programs.

NIST Concrete Research and Infrastructure

Concrete is the most widely used building material in the world, playing a principal role in transportation infrastructure such as bridges and roadways by providing strength, durability, and resiliency. NIST has been doing research to support the concrete industry for over 60 years.

The strength and reliability of buildings, bridges and roadways can be linked to the performance of a key component of concrete: cement—a fine powder of limestone, clay, sand and gypsum. When mixed with water, it creates a paste that can bind sand and rock together and harden into concrete. Manufacturers strive for uniformly reliable cement, relying on standard test methods developed and validated through the American Society for Testing and Materials (ASTM) International.

To support the development, usability, accuracy, and precision of consensus standards, NIST offers more than 20 types of cement standard reference materials (SRM®). The standard test methods supported by NIST SRMs ensure quality cement products and the integrity of structures around the globe. For example, SRM 46h, the Portland Cement Fineness Standard, is essential to the calibration of fineness testing equipment according to ASTM Standard Methods. SRM 2492, the Bingham Paste Mixture for Rheological Measurements, provides a well-characterized mixture to calibrate rheometers for measuring the rheological, or flow, properties of concrete. Well-characterized rheological properties are crucial to ensuring the ability to pump concrete on

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[7] For more information about success stories from communities using the Guide, see https://www.nist.gov/topics/community-resilience/nist-community-resilience-planning-guide-success-stories.

job sites. SRM 1881b, Portland Cement Blended with Fly Ash, is used to validate chemical and instrumental methods of analysis of cements and materials of similar matrix for elemental content. Fly ash is a byproduct of burning coal for power generation. Previously considered a waste byproduct, research indicates that fly ash can be used to create improved cement that requires less water to mix into concrete, sets faster, flows more easily through pumps, and creates a stronger and less permeable concrete. The fly ash cement SRM is an example of how NIST continues to respond to the evolving needs of the $1 trillion global cement industry.

Additive Manufacturing with Cement and Concrete

Additive Manufacturing (AM) with cement-based materials is an emerging technology that offers exciting new opportunities in the construction industry. Robotic arms have been used to automate casting of concrete into formwork, and computer-controlled gantry cranes have been adapted to dispense material in a layer-by-layer method. Rapid construction enabled by AM techniques has many possible applications and benefits, including rapidly constructed shelters for communities after natural disasters (i.e., automated military construction with local materials), reduced transportation costs by on-site printing of bridge components, taller wind towers to access higher energy winds, more cost-effective design strategies through precise control of materials, and new methods to repair concrete in hard-to-reach areas.

AM with cement-based materials represents a paradigm shift in the approach to concrete specification and quality control and assurance. Metrology and standards used for traditional concrete construction are not suitable for AM, as precise measurements of a material's rheology before and during construction are required. NIST is conducting a combination of experimental measurements, numerical simulations, and machine learning (ML) techniques to assess the potential of various material systems for AM. Artifacts will be constructed using two AM robots: one bench-scale robot for paste and one construction-scale robot for grout. Non-destructive testing techniques will be used to assess a structure's build quality by detecting defects such as cold joints. In addition, numerical simulations of paste and mortar flow will provide insight into the stresses experienced by the material during the AM and will inform rheology experimental protocols. Finally, to aid in material and process parameter selection, data collected during this project will be used to train ML algorithms to predict combinations that produce high-quality AM structures.

Interest in AM with cement-based materials is quite high, and collaborations are being developed to ensure that solutions will be applicable to the construction field. NIST will participate in the *First International Conference on 3D Printing and Transportation*, sponsored by the Transportation Research Board of the National Academy of Sciences, Engineering and Medicine, in November 2019.[8] NIST will also lead a task group in the American Concrete Institute that will coalesce industrial standards needs in cement-based AM. Finally, NIST is

[8] http://www.trb.org/Calendar/Blurbs/177388.aspx

establishing a consortium of industry and academia partners to identify measurement science needs to advance adoption of cement-based AM technology.[9]

Advanced Composites in Infrastructure

The American Society of Civil Engineers 2017 Infrastructure Report Card delivered a D+ grade to U.S. infrastructure, stating that $2 trillion in funds would be needed to bring our critical infrastructure up to grade and calling for "new approaches, materials, and technologies to ensure our infrastructure is more resilient." Knowing that NIST frequently provides a neutral forum where industry members can speak candidly about challenges, the American Composites Manufacturers Association (ACMA) asked us to help convene the composites community to identify barriers for new materials in infrastructure. Advanced composites may in certain applications be stronger, lighter, and longer lasting than traditional building materials, thereby offering many cost savings. For example, it may take less fuel to transport lighter components, the equipment required to assemble advanced composite components into bridges or other structures may be lighter, and advanced composites may better resist corrosion from weather and exposure to chemicals. Longer lifespans for infrastructure components would mean fewer service days lost to maintenance of the bridges, roads, dams, levees, highways, railroads, utility poles, and other elements that support movement of the goods and services that underpin our economy.

Disaster and Failure Studies

Buildings, bridges, and other man-made structures fail due to a variety of reasons, including high winds, fires, earthquakes, errors in design and construction, flaws in materials, and even terrorist attacks. The NIST Disaster and Failure Studies Program establishes teams to assess building and infrastructure performance in the wake of disaster and failure events that have resulted in substantial loss of life or posed significant potential for substantial loss of life.

The objectives of NIST's disaster and failure studies may include (1) establishing the likely technical factor or factors responsible for the damage, failure, and/or successful performance of buildings and/or infrastructure in the aftermath of a disaster or failure event; (2) evaluating the technical aspects of evacuation and emergency response procedures that contributed to the extent of injuries and fatalities sustained during the event; (3) determining the procedures and practices that were used in the design, construction, operation, and maintenance of the buildings and/or infrastructure; and (4) recommending, as necessary, specific improvements to standards, codes, and practices as well as any research and other appropriate actions based on study findings.

NIST studies are documented in technical reports containing data, findings, and recommendations for consideration by: private sector bodies responsible for developing national model codes, standards, and/or practices; federal, state and local officials for adoption and enforcement of national model codes and standards; and research-performing organizations such as universities, national laboratories, and private sector entities. By identifying the technical

[9] More information on the MACE Consortium can be found at https://www.federalregister.gov/documents/2018/05/22/2018-10913/nist-consortium-for-metrology-of-additive-construction-by-extrusion-mace

causes leading to building or infrastructure failures, making that information public, and then promoting and tracking adoption of recommendations, NIST engineers and scientists seek to prevent similar failures in the future. Studies previously conducted by NIST have led to significant changes in practices, standards, and codes to enhance the health and safety of the American public.[10]

NIST Hurricane Maria Program

NIST is currently investigating the effects of Hurricane Maria in Puerto Rico.[11] On September 20, 2017, Hurricane Maria made landfall in Puerto Rico, damaging infrastructure that its communities relied on for medical care, safety, mobility, communications, and more. To better understand how the buildings and infrastructure failed, and how we can prevent such failures in the future, NIST began to study how critical buildings and infrastructure systems performed during the storm.

In Puerto Rico, NIST will seek to understand Hurricane Maria's wind environment and the conditions that led to injuries and deaths; how critical buildings and designated safe areas within them performed—including their dependence on electricity, water, transportation, and other infrastructure; how emergency communications systems performed and the public's response to such communications; and the impacts to, and recovery of, selected businesses, hospitals and schools, as well as the critical social functions they provide.

National Windstorm Impact Reduction Program

The purpose of the National Windstorm Impact Reduction Program (NWIRP) is "to achieve major measurable reductions in the losses of life and property from windstorms through a coordinated Federal effort, in cooperation with other levels of government, academia, and the private sector, aimed at improving the understanding of windstorms and their impacts and developing and encouraging the implementation of cost-effective mitigation measures to reduce those impacts."[12] In addition to NIST, which is designated as the lead agency, other NWIRP agencies include FEMA, the National Oceanic and Atmospheric Administration (NOAA), and the National Science Foundation (NSF). The Federal Highway Administration (FHWA) has also participated in NWIRP from its inception.

Lead agency responsibilities at NIST include ensuring that the Program includes the necessary components to promote the implementation of windstorm risk reduction measures; supporting the development of performance-based engineering tools, and working with appropriate groups to promote the commercial application of such tools; coordinating all Federal post-windstorm

[10] For more information on some of the impacts that NIST Disaster and Failure Studies have had on building codes, standards, and practices, see https://www.nist.gov/topics/disaster-failure-studies/impacts-and-recommendations.
[11] A public announcement of the Hurricane Maria study can be found at: https://www.nist.gov/news-events/news/2018/05/nist-launches-study-hurricane-marias-impact-puerto-rico
[12] National Windstorm Impact Reduction Act Reauthorization of 2015, Public Law 114-52, codified at 42 U.S.C. 15701 *et seq*., can be found at https://www.congress.gov/114/plaws/publ52/PLAW-114publ52.pdf.

investigations to the extent practicable; and when warranted by research or investigative findings, issuing recommendations to assist in informing the development of model codes. In addition to lead agency responsibilities, NIST conducts research and development to reduce windstorm losses by transferring science and engineering knowledge to committees and organizations responsible for model building codes, voluntary standards, and best practices for the design, construction, and retrofit of buildings, structures, and lifelines, including transportation infrastructure.

As required under the 2015 reauthorization, windstorm loss reduction strategies, including research needs, are assessed in the *Strategic Plan for the National Windstorm Impact Reduction Program*.[13] Specific to transportation infrastructure, Objective 5 of that strategic plan identifies the need to advance understanding of windstorm effects on the built environment, including an improvement in the understanding of civil infrastructure vulnerabilities in extreme windstorm events and refinement of computational tools to predict performance of civil infrastructure, including transportation systems. Objective 8 identifies the emerging need to understand how windstorms impact communities as a whole – for example, data collection on characteristics of the emergency response and also recovery times for return to functionality for critical facilities and key infrastructure, such as hospitals, power, and transportation networks.

Conclusion

NIST has a long history of addressing the Nation's needs through measurement science. Resilient infrastructure, particularly transportation, is the backbone of U.S. economic competitiveness and NIST is proud to collaborate with industry, academia, and government agencies to meet critical national needs.

We greatly appreciate the efforts of the members of these committees and other members of Congress to support resilience programs that keep the Nation globally competitive and secure, and that contribute to our quality of life.

I will be pleased to answer any questions you may have.

[13] The 2018 NWIRP Strategic Plan can be found at https://www.nist.gov/sites/default/files/documents/2018/09/24/nwirp_strategic_plan.pdf.

Jason D. Averill

Jason D. Averill is Chief of the Materials and Structural Systems Division (MSSD) of the Engineering Laboratory (EL) at the National Institute of Standards and Technology (NIST).

Since joining the Engineering Laboratory in 1997, Mr. Averill has focused his research on making communities safer and more resilient to hazards.

Mr. Averill is a member of the American Society of Civil Engineers, has served on the International Code Council's Means of Egress Committee, the NFPA Life Safety Code Committee (Means of Egress), and was a member of the ASME A17 Task Group developing guidelines for Occupant and Firefighter Use of Elevators During Fire Emergencies.

In 2005, Mr. Averill received the U.S. Department of Commerce Gold Medal Award for Distinguished Achievement in the Federal Service for his work on the Federal Investigation of the Collapse of the World Trade Center Buildings. In 2011, Mr. Averill received the U.S. Department of Commerce Silver Medal for characterizing the deployment of firefighting resources and in 2004 received the U.S. Department of Commerce Bronze Medal Award for Superior Federal Service for research into the characterization of the performance of home smoke alarms

The Materials and Structural Systems Division serves as the world-class resource for developing and promoting the use of science-based tools – measurements, data, models, protocols, and reference standards – to enhance both the global competitiveness of U.S. industry through innovations in building materials and construction technology; and the safety, security, and resilience of the nation's buildings and physical infrastructure. In addition to NIST measurement science research, the Division is also responsible for managing three statutory programs, including the National Earthquake Hazard Reduction Program (for which NIST is the lead agency), the National Windstorm Impact Reduction Program (for which NIST is the lead agency), and the National Construction Safety Team Program.

Education

M.S. in Fire Protection Engineering from Worcester Polytechnic Institute

B.S. in Civil Engineering from Worcester Polytechnic Institute