

**National Institute of Standards and Technology
National Construction Safety Team Act
Annual Report
Fiscal Year (FY) 2020**

Summary

This annual report to Congress for Fiscal Year (FY) 2020 is required by the National Construction Safety Team (NCST) Act (Public Law 107-231). The National Institute of Standards and Technology (NIST) continues to evaluate Hurricane Maria's impacts on Puerto Rico as part of the NCST investigation launched by the NIST Director on February 21, 2018. The goals of this investigation are to characterize: (1) the wind environment and technical conditions associated with deaths and injuries; (2) the performance of representative critical buildings, and designated safe areas in those buildings, including their dependence on local lifelines; and (3) the performance of emergency communications systems and the public's response to such communications.

In FY 2020, NIST did not deploy any preliminary reconnaissance teams because of the safety concerns associated with the COVID-19 pandemic. The safety concerns were included as a qualitative criterion in the evaluation in the event scoring process. However, NIST engaged in two virtual reconnaissance efforts and worked with NIST Disaster Resilience Research Grantees to collect data of interest for further assessment of four events. The observations from these preliminary reconnaissance efforts did not result in any new NCST technical investigations.

The NCST World Trade Center Investigation¹ and the NCST Joplin Tornado Investigation² resulted in recommendations to develop consensus standards and code provisions related to progressive collapse and tornado resistant design, and NIST is continuing to implement those recommendations.

Highlights of FY 2020 activities include:

- NIST made significant progress in data collection and modeling to support each project of the NCST Hurricane Maria Investigation;
- NIST awarded a contract to the Horsley Witten Group to support social science data collection efforts in Puerto Rico, including data collection focused on emergency communications messaging and the public response to those messages during and immediately after Hurricane Maria;
- NIST awarded a contract to Stantec Consulting Services to support evaluation of the performance of critical buildings during Hurricane Maria;
- NIST awarded a contract to the George Washington University to support the project focused on identifying direct and indirect deaths caused by Hurricane Maria and, more specifically, those deaths attributed to building and/or building system failure(s);
- NIST and the National Science Foundation (NSF) created a joint solicitation (NSF 20-581³, Disaster Resilience Research Grants) that serves as NIST's 2020 Notice of Funding Opportunity to solicit Disaster Resilience Research Grants to advance fundamental

¹ Report available at: http://www.nist.gov/customcf/get_pdf.cfm?pub_id=909017.

² Report available at: http://www.nist.gov/customcf/get_pdf.cfm?pub_id=915628.

³ DRRG solicitation available at: <https://www.nsf.gov/pubs/2020/nsf20581/nsf20581.htm>

understanding of disaster resilience in support of improved, science-based planning, policy, decisions, design, codes, and standards. This solicitation is designed to help both agencies better meet their statutory responsibilities (including NCST), as well as their overall missions;

- NIST completed development of the first-ever engineering-derived probabilistic tornado wind speed maps produced for the United States for use in tornado-resistant design of buildings, which addresses Recommendation #3 from the NCST Joplin Investigation;
- NIST continued to work with the American Society of Civil Engineers (ASCE) Structural Engineering Institute (SEI) Standards Committee that is developing the new Tornado Wind Speed Estimation Standard, which directly addresses Recommendation #4 from the NCST Joplin Investigation;
- NIST supported the development of the next edition of the International Code Council (ICC) 500 Standard for Design and Construction of Storm Shelters, which will include a large number of improvements for tornado shelter standards, which directly addresses Recommendation #7a from the NCST Joplin Investigation; and
- NIST contributed to the committee balloting and associated revisions for a draft consensus standard for disproportionate collapse mitigation of building structures, which addresses Recommendation #1 from the WTC Investigation.

NIST presented the FY 2020 activities to the NCST Advisory Committee (NCSTAC or Committee) via web conference on June 30 - July 1, 2020 and October 23, 2020. NIST briefed the NCSTAC on:

- NIST's response to the Committee's FY 2019 report to Congress;
- Progress of NIST implementation of the NCST Joplin Investigation recommendations;
- Progress on the NCST Investigation of Hurricane Maria's impacts on Puerto Rico, including stakeholder outreach, establishment of information sharing agreements, and supporting contracts, coordination of sampling strategies across projects, data collection for the evaluation of critical buildings and public response to emergency communications, advancements in the wind tunnel modeling work and the deployment of anemometers for collecting field measurements to evaluate topographic effects on winds;
- Related studies of Hurricane Maria under the NWIRP authority;
- Disaster and failure events scored using the preliminary reconnaissance screening criteria; and
- Other NIST efforts, under the Disaster and Failure Studies Program, that enhance the readiness of National Construction Safety Teams (Teams).

The NCSTAC:

- highlighted the need for the studies of the performance of critical buildings, infrastructure, and supply chains in Hurricane Maria to consider some measurement of functional recovery to develop timelines and planning guidelines not only for these important systems, but for the community at large;
- commended NIST's diverse team of researchers in a range of critical areas, including hazard characterization, performance of buildings and critical infrastructure, risk communication, business and supply chain logistics, and health and medicine;
- acknowledged the value of NIST's engagement and inclusion of local scientific and professional talent from Puerto Rico in the investigation;

- applauded the actions linking the disparate parts of this study together, such as the combined efforts of social science and engineering, which are likely to offer new insights that could not be accomplished without collaboration between the two disciplinary spaces;
- recognized the necessity of a purposeful and deliberate process in coordinating and subcontracting various aspects of the investigation and the positive outcome of this approach;
- encouraged continued collaboration with experts in data-driven science to progress efforts to secure and manage disaster-related data;
- suggested the consideration of alternative means for systematic data collection that can be implemented in a timely fashion that are not reliant upon face-to-face, in-person research methods;
- urged coordination of NCST data collection efforts with the National Windstorm Impact Reduction Program (NWIRP) researchers who are focused on the physical performance of wireless communication systems as these systems are critical infrastructure for both response and recovery;
- suggested that the NCST should be prepared for counterproposals to the current NIST proposal for tornado resistant design, which prescribes tornado wind speeds that are proportional to building size (due to the increased tornado strike probability for buildings with larger plan areas), in case this new approach is not universally accepted;
- observed that achieving tornado resistance in wood-frame residential construction would require a thorough study of tornado losses and cost-effective methods to reduce such losses;
- encouraged NCST to continue to explore alternative strategies for the protection of life during tornadoes, especially the improvement of tornado shelter standards and public tornado sheltering strategies;
- suggested the importance of ongoing efforts to make investigation findings in the form of practical guidance, including messaging templates for emergency managers to communicate under imminent threat, available to risk communicators to aid in effective messaging for populations at risk;
- recommended continued perseverance with obtaining and analyzing social media data for future research endeavors; and
- emphasized the need to quickly collect and document time-sensitive data with future NCST activities, and suggested looking to other entities (e.g., the National Transportation Safety Board) that may have developed protocols for quick response activities.

A summary of these meetings may be found on the NIST NCST website⁴ and in the FY 2020 Annual Report of the NCSTAC to Congress.⁵

⁴ NCSTAC meeting agendas, presentations, and summaries are available at:

<https://www.nist.gov/topics/disaster-failure-studies/national-construction-safety-team-ncst/advisory-committee-meetings>.

⁵ FY 2020 NCSTAC Report to Congress available at: <https://www.nist.gov/topics/disaster-failure-studies/national-construction-safety-team-ncst/advisory-committee>.

Introduction

In October 2002, the NCST Act was signed into law by President George W. Bush and authorized the Director of NIST to establish and deploy Teams to investigate events leading to failure of a building, or buildings, that resulted in substantial loss of life or that posed significant potential for substantial loss of life.

The purpose of these investigations is to improve the safety and structural integrity of buildings in the United States. A Team shall:

1. Establish the likely technical cause or causes of building failure;
2. Evaluate the technical aspects of evacuation and emergency response procedures;
3. Recommend, as necessary, specific improvements to building standards, codes, and practices based on the findings made pursuant to (1) and (2); and
4. Recommend any research and other appropriate actions needed to improve the structural safety of buildings, and improve the evacuation and emergency response procedures, based on the findings and recommendations of the investigation.

Under Section 10 of the NCST Act, NIST is to provide an annual report to the House Committee on Science, Space, and Technology, and to the Senate Committee on Commerce, Science, and Transportation each year. This report is to include:

1. A summary of the investigations conducted by Teams during the prior fiscal year;
2. A summary of recommendations made by the Teams in reports issued under Section 8 of the NCST Act during the prior fiscal year and a description of the extent to which those recommendations have been implemented; and
3. A description of the actions taken to improve building safety and structural integrity by NIST during the prior fiscal year in response to reports issued under Section 8 of the NCST Act.

This report summarizes NIST's activities under the NCST Act for FY 2020 as required by Section 10 of the Act.

1. Investigations Conducted Under the NCST Act during FY 2020.

On September 20, 2017, Hurricane Maria made landfall in Puerto Rico as a strong Category 4 storm, causing fatalities, injuries, and damage to buildings and infrastructure. The NIST Director established a Team under the NCST Act, based on an analysis of the event against the criteria in the NCST Act and its implementing regulations (15 C.F.R. Part 270), to conduct a technical investigation of the building performance and emergency response and evacuation during Hurricane Maria. The goals of the NCST Hurricane Maria Investigation are to characterize: (1) the wind environment and technical conditions associated with deaths and injuries; (2) the performance of representative critical buildings, and designated safe areas in those buildings, including their dependence on lifelines; and (3) the performance of emergency communications systems and the public's response to such communications.

The Team members continue to work on four projects related to the investigation:

- (1) Hazard Characterization.

The objective of this project is to characterize the wind environment associated with Hurricane Maria's impact on Puerto Rico, including topographic effects, and to document other hazards associated with the hurricane, including storm surge, rainfall, flooding, and landslides in order to understand subsequent building failures. The investigative methods for this project include wind field modeling, wind tunnel testing, field measurements, and numerical simulation.

The wind field modeling is supported by a contract awarded in February 2019 to Applied Research Associates, which includes the development of a time-dependent wind field model of Hurricane Maria's impact on Puerto Rico. In FY 2020, improvements to the initial wind field model have been made through the development of a methodology to better adapt the model to strongly asymmetric wind fields and a methodology to optimize how the model fits the observed data, with quantification of uncertainty. These methodologies have been evaluated using data from other hurricanes, including Hurricanes Irma and Michael. The improved methodologies will enhance the final version of the wind field model for Hurricane Maria. The final wind field model will also incorporate refined modeling of topographic effects based on wind tunnel and numerical results.

The wind tunnel testing and field measurement of winds is supported by a contract with the University of Florida, awarded in May 2019. In FY 2020, NIST, with support from the University of Florida and its subcontractors, made significant progress in evaluating topographic effects on winds. The testing plan has been completed for wind tunnel testing of generic two-dimensional topographic models, and the generic topographic models have been fabricated. Models with three types of surface roughness will be tested: smooth, rough, and terraced. The testing plan has been completed for wind tunnel testing of scale models of the Mayagüez and Yabucoa regions in Puerto Rico. Fabrication of the Yabucoa model was completed, and fabrication of the Mayagüez model was underway at the end of FY 2020. Flow measurements in the wind tunnel have been completed to characterize the incoming flow profile for different terrain categories, and to ensure that incoming flow matches the target profile. Testing of topographic models is currently underway, and measurements have been completed for a subset of the tests. Three cell towers in the Yabucoa region were selected for field measurement of topographic speedup effects, and a deployment plan was developed for installation of anemometers at multiple heights on each tower, with space on the towers provided by American Tower Corp., the owner of the towers. Anemometers were installed on the three selected tower sites by WeatherFlow, a NIST subcontractor. The Team has started to record wind speed data, including capture of high wind data from Tropical Storm Isaiás in July 2020 and Tropical Storm Laura in August 2020.

The Team has been developing Computational Fluid Dynamics (CFD) models for generating approach flows and accounting for terrain surface roughness, including trees, in order to achieve improved accuracy in simulations of topographic effects on winds. The Team employed the CFD models to evaluate effects of a guide wall system on the flow field in the University of Florida wind tunnel. The detailed information from the numerical simulations led to a modification of the guide wall system to enhance the quality of the experimental approach flow in the testing

section. The Team has started to perform simulations of flow over the generic topographic models for validation of the CFD models through comparison with the corresponding experimental datasets, which will be completed in FY 2021. The validated CFD models will be used to simulate wind over regions in Puerto Rico to support the evaluation and characterization of topographic effects on the wind velocity field in Hurricane Maria.

(2) Performance of Critical Buildings.

The objective of this project is to characterize the performance of critical buildings in Hurricane Maria by evaluating damage and loss of function for representative hospitals, schools, and storm shelters with respect to the hazards they experienced and by evaluating the selection criteria and design requirements for storm shelters.

Support in evaluating the performance of critical buildings is being provided through a contract awarded to Stantec Consulting Services, Inc., on March 3, 2020. Key personnel on the Stantec team include engineering experts based in Puerto Rico. The contractor is documenting the performance of selected critical facilities, including hospitals, schools, and storm shelters during Hurricane Maria. Document review and site visits will be complemented by interviews with key personnel at these facilities. Building characteristics being reviewed include facilities' structural and nonstructural components (e.g., type of roof covering, type of structural system, and type of windows, doors, and opening protective systems), age (e.g., date of construction and building code used for design), utility redundancies (e.g., the capacity of any existing backup generators and emergency water supplies), and mitigation efforts before the hurricane's landfall (e.g., sandbagging and anchoring of rooftop equipment). Data on damage (e.g., to the envelope, roofing system, structural system, rooftop equipment, etc.) will help to identify trends in structural performance by occupancy type, construction era, and structural system. Stantec will also collect data on the facilities' functionality immediately following landfall, including relocation of services and/or building occupants, status of availability of lifelines in the following days, and hazardous conditions encountered by building occupants. In FY 2020, the NIST team collected and evaluated information on building characteristics, hazard exposure, and damages for hospitals, schools, and storm shelters in Puerto Rico, and a sampling strategy was developed to select facilities for detailed evaluation based on consideration of the available information. Five hospitals were selected, and the Stantec team initiated detailed evaluation efforts for these facilities, which included collection and review of documents such as architectural drawings and damage assessment reports. For one of these hospitals, in a region where the topography results in significant speed-up of winds, the Stantec team conducted drone photography of the hospital site to provide detailed information on the dimensions of the buildings on site and surrounding area. This information is being used to support fabrication of a scale model of the facility for wind tunnel testing planned in FY 2021 through the contract with the University of Florida.

(3) Public Response to Emergency Communications.

The objective of this project is to investigate the role of emergency communications in public response for those under imminent threat from Hurricane Maria. This

project will also examine the use of communications during response and recovery (during and immediately after the hurricane).

A contract to support this project, as well as related NWIRP projects, was awarded on December 12, 2019, to Horsley Witten Group, Inc., which will be aided by subcontractors Eastern Research Group, Inc., Issues & Answers, Inc., and Albizu University in Puerto Rico. The contractors will support the Public Response to Emergency Communications project by surveying households in regions at risk of floods and interviewing officials who provided emergency information to the public to better understand factors that influenced households to evacuate or not to evacuate, and the role emergency communications played in those decisions.

The surveys will be conducted with sampled households (1,500 respondents) within four emergency management regions (or zones) within Puerto Rico, identified by NIST. A sampling plan has been developed to ensure appropriate response across demographic variables as well as risk exposure to flooding and landslide conditions. The survey will ask households about pre-Hurricane Maria activities and perceptions, including previous experience with hurricanes, pre-event risk perception, and knowledge of risk zones; the types of emergency information sought/received before and during the hurricane; their perceptions of this information as well as other environmental and social cues; protective action decisions; information needs during and after the event; and health or medical care needs after the hurricane. From the survey respondents, a small sample will be identified to participate in follow-up open-ended, semi-structured interviews. NIST will also conduct open-ended, semi-structured interviews with Commonwealth, regional and/or local emergency managers; National Weather Service officials, broadcast meteorologists and other members of the media, and others responsible for communication with the public. The goal of these interviews is to better understand pre-hurricane preparation and planning; situational awareness prior to and during the event; decisions made about communicating with the public; and lessons learned that may have led to changes in communication-related policies, procedures and/or guidelines. Drafts of preliminary data collection instruments have been developed and are expected to go to the Office of Management and Budget (OMB) for Paperwork Reduction Act approval in FY 2021.⁶

(4) Characterization of Morbidity and Mortality.

The objective of this project is to complete a quantitative morbidity and mortality assessment of Puerto Rico, to better understand how damaged buildings and supporting infrastructure played a role in the injuries and deaths associated with Hurricane Maria. The study results will provide guidance to improve codes and standards as well as to inform future approaches to accurately attribute and predict life loss due to windstorm building failure(s).

A contract was awarded on July 27, 2020, to the Milken Institute School of Public Health at the George Washington University (GW), with collaborating team

⁶ Prior to the submission of this report, OMB approved information collections for the pilot test of the household survey and for the full implementation of the information provider interview under the NIST Generic Clearance for Community Resilience Data Collections, OMB Control #0693-0078, Expiration Date: 07/31/2022.

members at the University of Puerto Rico-Graduate School of Public Health (UPR), and the Institute for Health Metrics and Evaluation (IHME) at the University of Washington. The contractors will support the Morbidity and Mortality Project's goal of identifying deaths in Puerto Rico directly and indirectly related to Hurricane Maria and, more specifically, to identify deaths attributed to building and/or building system failure(s).⁷ The GW Biostatistics Center statisticians have started to design an integrated database structure and to link data from various data sources on the deaths that occurred up to six months after Hurricane Maria made landfall in Puerto Rico. The GW geospatial analysis team have begun geocoding the addresses provided in the death certificate data, and have been able to match more than 70% of deaths with the location of death. GW also began an assessment of address components for unmatched addresses to determine geocoding potential. Based on the integrated database, the University of Puerto Rico (UPR) School of Public Health, a subcontractor to GW, will survey next-of-kin or other key informants using a Verbal Autopsy and Socio-Environmental (VA+S'E) survey to determine attribution of deaths that occurred immediately after the storm made landfall. The GW VA+S'E group has nearly completed a scoping literature review and have begun gathering instruments to develop a question bank.

In order to support all of the projects outlined above, Team members traveled to Puerto Rico in October and November 2019. Members of the Team held follow-up meetings with officials from Puerto Rico government departments and agencies in the study areas, university partners, as well as FEMA's Office of Response and Recovery within the Joint Recovery Office in Puerto Rico and other U.S. government officials. The Team also conducted site visits focused on collecting the data and information needed for the investigation. In November 2019 and March 2020, Memorandums of Agreement were signed between NIST and FEMA to share information on damage to schools and hospitals.⁸

Team members also directly and indirectly contributed to a number of FEMA efforts related to the NCST Hurricane Maria Investigation. NIST feedback to the Puerto Rico Mitigation Assessment Team informed FEMA's Prescriptive Residential Designs for Puerto Rico⁹ (August 2020). NIST also provided extensive stakeholder feedback on FEMA P-2062, *Guidelines for Wind Vulnerability Assessments of Existing Critical Facilities (September 2019)*, FEMA's *Best Available Refuge Area Assessment Guide for Puerto Rico Hurricane Wind Hazards Job*

⁷ Under 15 CFR § 270.100(b), "a building failure may involve one or more of the following: structural system, fire protection (active or passive) system, air-handling system, and building control system. Teams established under the Act and this part will investigate these technical causes of building failures and will also investigate the technical aspects of evacuation and emergency response procedures, including multiple-occupant behavior or evacuation (egress or access) system, emergency response system, and emergency communication system."

⁸ The MOAs were completed in November 2019 and March 2020. The first Memorandum of Agreement between FEMA and NIST for FEMA DR 4339 PR Information Sharing and Management is focused specifically on data and information related to the Education and Health and Human Services Public Assistance Program. The second Memorandum of Agreement between FEMA and NIST for FEMA DR 4339 PR Information Sharing and Management is focused specifically on data and information related to hospital and school assessment data with NIST through Grants Manager.

⁹ Four (4) Prescriptive Design Sets for Affordable Single-Family Homes based on the 2018 Puerto Rico Building Code were published. Each set contains over 25 drawing sheets with house plans, sections, elevations, details, and notes. ICC-500 safe rooms and Puerto Rico SWR requirements are incorporated into the multi-hazard designs.

Aid (September 2019), and FEMA P-2054, *Mitigation Assessment Team Compendium Report - 2017 Hurricane Season* (September 2019).

In February 2020, Dr. Joseph Main (NIST) was appointed the Lead Investigator (formerly Associate Lead Investigator) and Dr. Maria Dillard (NIST) was appointed the Associate Lead Investigator. These leadership changes followed the departure of Dr. Erica Kuligowski from NIST. The following new members were appointed¹⁰ by the NIST Director to the NCST for the Hurricane Maria Investigation:

Dr. DongHun Yeo, Team Member

Affiliation: Research Structural Engineer, Structures Group, EL, NIST

Relevant Areas of Expertise: extreme wind climatology, atmospheric boundary-layer winds, bluff-body aerodynamics, computational fluid dynamics, wind tunnel testing, and advanced analysis of structural performance under wind loads.

Mr. Joel Cline, (outside) Team Member

Affiliation: Tropical Program Coordinator, National Weather Service, NOAA

Relevant Areas of Expertise: tropical weather hazards, hurricane winds and coastal inundation, operational hurricane forecasting, risk communication, and post-hurricane assessment of communication activities.

Dr. Katherine Johnson, Team Member

Affiliation: Social Scientist and Earthquake Risk Mitigation Policy Analyst, Earthquake Engineering Group, EL, NIST.

Relevant Areas of Expertise: Social science and earthquake risk mitigation policy analysis.

Dr. Luis Aponte, (outside) Team Member

Affiliation: Federal Contractor, Stantec and Professor, Department of Civil Engineering and Surveying, University of Puerto Rico at Mayagüez

Relevant Areas of Expertise: Measurements and modeling of the wind environment in Puerto Rico and documentation of the performance of buildings through post-hurricane damage assessments.

These new members supplement the Team's expertise in wind hazard measurement and modeling, tropical weather hazards, emergency communications, and building performance.

Updates on the NCST Hurricane Maria Investigation are posted frequently on the NIST website.¹¹

2. Summary of Recommendations Made by Teams in Reports Issued Under Section 8 of the NCST Act during FY 2020.

During FY 2020, NIST did not issue a report under Section 8 of the NCST Act.

¹⁰ The appointments of Yeo and Cline occurred in late FY 2019; the appointments of Johnson and Aponte occurred in FY 2020.

¹¹ NIST Hurricane Maria website: <https://www.nist.gov/topics/disaster-failure-studies/hurricane-maria>.

3. Actions Taken to Improve Building Safety and Structural Integrity During FY 2020 in Response to Reports Issued Under Section 8 of the NCST Act.

During FY 2020, NIST did not issue a report under Section 8 of the NCST Act.

a. Actions Related to Report on the NIST World Trade Center Investigation:

The following recommendations in the final report of the Collapse of the World Trade Center Towers^{Error! Bookmark not defined.} were addressed in FY 2020 to improve building safety and structural integrity:

- In FY 2012, based on a proposal from NIST, a new ASCE SEI Standards Committee was established to develop a consensus standard for disproportionate collapse mitigation of building structures, which addresses Recommendation #1 from the WTC Investigation. This voluntary committee has developed a complete draft of the new standard, with substantial contributions from four NIST staff who have informed the standard with the results of NIST research. In FY 2020, the committee completed revisions to the draft standard in response to comments from the third and fourth committee ballots. A fourth and fifth committee ballot were also initiated in FY 2020. A public ballot of the standard is planned after the completion of committee balloting.

b. Actions Related to Report on the NIST Joplin Tornado Investigation:

The following actions were taken in FY 2020 to implement recommendations in the NCST Joplin Investigation final report^{Error! Bookmark not defined.} to improve building safety and structural integrity:

- NIST completed development of the tornado hazard maps for use in tornado-resistant design of buildings. These maps are the first ever engineering-derived probabilistic tornado wind speed maps produced for the United States. This completion fulfills NIST Joplin Recommendation #3 (of Recommendations Group 1, Tornado Hazard Characteristics and Associated Wind Field) and provides the prerequisite technical underpinning to support NIST Joplin Recommendations #5 and #6 (of Recommendations Group 2, Performance of Buildings, Shelters, Designated Safe Areas, and Lifelines, in the final report^{Error! Bookmark not defined.}).
- NIST continued to work with the ASCE SEI Standards Committee that is developing the new Tornado Wind Speed Estimation Standard. The American Meteorological Society (AMS) is also engaged in this effort, and the standard will be a joint ASCE/SEI/AMS document when completed. The committee, co-chaired by National Oceanic and Atmospheric Administration (NOAA) and NIST staff, is developing standardized methods for estimating the wind speeds in tornadoes and other severe windstorms, including significant improvements to the Enhanced Fujita Scale. During FY 2020, the committee completed drafts of two additional chapters of the new standard on radar and forensic engineering methods, and began balloting those chapters through the ASCE SEI Standards Committee, as well as continuation of work on chapters for other wind speed estimation methods. This standards development activity directly addresses NIST Joplin Recommendation #4 and supports NIST Joplin Recommendations #1 and #2 (of Recommendations Group 1, Tornado Hazard Characteristics and Associated Wind Field, in the final report^{Error! Bookmark not defined.}).

- NIST staff continued to lead the Tornado Task Committee within the ASCE 7-22 Wind Load Subcommittee (*ASCE 7: Minimum Design Loads and Associated Criteria for Buildings and Other Structures*). This committee completed the development of the tornado wind load design methodology and standards provisions, incorporating the NIST tornado hazard maps and other research to create a new chapter on Tornado Loads for ASCE 7-22. As of the end of FY 2020, this new chapter had passed the ASCE 7 Wind Load Subcommittee and was under consideration by the ASCE 7 Main Committee. These efforts directly address NIST Recommendation #6 (of Recommendations Group 2, Performance of Buildings, Shelters, Designated Safe Areas, and Lifelines, in the final report^{Error! Bookmark not defined.}).
- NIST staff chairs the standards committee for the ICC 500 Standard for Design and Construction of Storm Shelters as part of work towards improving the tornado shelter standards that supports implementation of Joplin Recommendation #7. The next edition of the standard is nearing completion and will include many updates developed and proposed by NIST. Notable advances include: expansion of scope to encompass design and construction of shelters in existing buildings; a new 10,000-year mean recurrence interval hurricane shelter design wind speed map; new provisions for impact loads due to laydown hazards and falling debris hazards; and new load combinations. The next edition of ICC 500 will also include a new appendix on emergency operations planning for storm shelters. These efforts directly address NIST Recommendation #7a (of Recommendations Group 2, Performance of Buildings, Shelters, Designated Safe Areas, and Lifelines, in the final report^{Error! Bookmark not defined.}).
- Ongoing activities include collaboration on a number of studies and products such as the update to FEMA P-320, *Taking Shelter from the Storm: Building or Installing a Safe Room for Your Home* (Expected 2021) and to FEMA P-361, *Safe Rooms for Tornadoes and Hurricanes: Guidance for Community and Residential Safe Rooms* (expected 2021).
- In addition to the actions described above, NOAA's National Severe Storms Laboratory (NSSL) has continued to make significant progress toward the development of new grid-based watch/warning hazardous weather forecasting capability for communicating probabilistic threats to advance the Forecasting a Continuum of Environmental Threats (FACETs) paradigm. This effort supports NIST Recommendation #16 (of Recommendations Group 3, Pattern, Location, and Cause of Fatalities and Injuries, and Associated Performance of Emergency Communications Systems and Public Response, in the final report^{Error! Bookmark not defined.}).

4. Preliminary Investigations

NIST uses a screening tool to assess the need for preliminary reconnaissance of disasters and failures. The screening tool utilizes the following key decision criteria: event consequences (substantial loss of life or disabling injury, significant potential for loss of life, hazard intensity, and consequences to resilience); major challenges in evacuation and/or emergency response; international factors (relevance to the United States); feasibility (resources and safety of team); and study impacts (new knowledge gains, and potential impact to existing standards, codes and guidelines). Twenty-three domestic and international events were scored in FY 2020, including seven windstorms, eight earthquakes, four structural failures, and four wildland-urban interface fires. None of the events scored in FY 2020 met the NIST preliminary deployment criteria for one or more of the following reasons: no clear study objectives that would impact standards, codes, and practices; unsafe conditions for NIST investigators; no primary authority or in-house expertise

of hazard type; construction practice and codes for international events are not similar to those used in the U.S.; no new lessons would be gained; or minimal impact to building occupants. As a result, NIST did not deploy teams in FY 2020 to collect preliminary reconnaissance data.

In order to minimize travel during the COVID-19 pandemic, NIST relied more heavily on virtual reconnaissance activities, as well as partners located in areas where events took place. NIST engineers joined virtual reconnaissance teams through the Earthquake Engineering Research Institute's Learning from Earthquakes Program for two phases of reconnaissance during the earthquake sequence in Puerto Rico. EERI's Virtual Earthquake Response Team (VERT) was activated during the Puerto Rico earthquake sequence that began in December 2019 and continued into 2020. NIST engineers served as authors on Phase 1 and Phase 2 reports of the VERT. Two grantee teams from NIST's Disaster Resilience Research Grants (DRRG) program - particularly those supporting development of sensors and methods to collect spatiotemporal data on windstorm phenomena, including surface-level winds and near ground velocity profiles in tornadoes, hurricanes, thunderstorms and other high wind events - deployed to four wind events and shared their data with NIST staff. In response to the tornadoes that touched down across Middle Tennessee during the early morning hours of March 3, 2020, resulting in widespread damage and numerous injuries and fatalities, NIST identified several areas of interest. These areas, informed by the ongoing implementation of recommendations of the Joplin Investigation, included the presence of tornado damage indicators in a highly urban area and impacts associated with the meteorological forecast and event timing on emergency response, protective action (e.g., sheltering, evacuation), and fatalities. In response, one team of academic researchers funded through the DRRG, coordinated with NIST and provided briefings following their reconnaissance. To calibrate wind field estimates, the grantee team collected data on tree-fall and other non-structural damage, including damage associated with roof aggregate. They also did detailed door-to-door structural assessments conducted by engineers along with interviews conducted by social scientists to capture residents' experiences. NIST also leveraged their efforts with those of National Windstorm Impact Reduction Program (NWIRP) partners (NOAA and FEMA¹²) for additional data on forecasts and response, as well as information sharing through the Recovery Support Function Leadership Group. These supplemental efforts allowed for enhanced decision making and further evaluation of the decision criteria. Despite the serious nature of each event, after assessing preliminary reconnaissance information from the supplemental efforts, NIST determined that these events did not meet the criteria for a formal NCST investigation.

5. Conclusion

The NCST Act authorizes NIST to establish and deploy Teams to investigate building failures that result in a substantial loss of life or pose significant potential for loss of life. In FY 2020, NIST assessed 23 events (fires, earthquakes, hurricanes, tornadoes, derecho, and structural failures) using a screening tool that considers: event consequences (substantial loss of life or disabling injury, potential for loss of life, hazard intensity and physical damage) and evacuation and/or emergency response; international factors (relevance to the U.S.); and study impacts (safety of team, new knowledge gains, and potential impact to existing standards, codes and guidelines). NIST contributed to two virtual reconnaissance teams and worked with some of its Disaster Resilience Research Grantees to collect data of interest for further assessment for four events.

¹² FEMA's Earthquake and Wind Programs Branch as well as Building Science Branch are participants in the NWIRP Windstorm Working Group.

After analyzing the data from Mexico, Louisiana, Texas, the Midwest, Puerto Rico, and Tennessee, NIST did not complete any preliminary deployments nor establish any new National Construction Safety Teams under the NCST Act. NIST continues to further investigate the building performance and emergency response and evacuation during Hurricane Maria in Puerto Rico, and continues to pursue actions related to improving building safety and structural integrity that were recommended by previous NCST investigations. NIST awarded several contracts to support the Performance of Critical Buildings project, the Public Response to Emergency Communications project, and the Characterization of Morbidity and Mortality project in FY 2020. NIST presented these FY 2020 activities to the NCST Advisory Committee during web-conference meetings in June 30 – July 1, 2020 and October 23, 2020.